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THE ANOMALOUS STRATIGRAPHY OF DEADMAN'S ISLAND, CALIFORNIA

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ABSTRACT

This article comprises an attempt to solve the problem of the anomalous occurrence of fossil remains of cold- and warm-water species of mollusks, etc., together in the three Pleistocene formations on Deadman's Island, California.

Solution comes from the discovery of two new groups of facts. First, the occurrence of the cold- and warm-water species in separate zones. Second, wherever species belonging to the two climatic extremes are associated, only one is autochthonous, the other is derived.

Conclusions on the interpretation of the sedimentary record of Deadman's Island are reached, especially with regard to the temperature represented by each deposit. The bearing of the results on correlation of the beds and of California Cenozoic deposits in general is considered.

INTRODUCTION

Deadman's Island is a small outlier of late Cenozoic marine deposits upon a basement of Miocene shales, lying half a mile off the port of San Pedro. The stratigraphy and paleontology of the deposits which form the island were dealt with by Arnold,[1] who produced a monograph embodying superb paleontological results but accompanied by an account of the stratigraphy which, like all pioneer work, leaves much to be desired. Other investigators have contributed information and discussion, but none have delved very deeply into the questions concerned with the stratigraphy of the deposits. Partly in consequence of this, certain erroneous ideas have

[1] R. Arnold, "The Paleontology and Stratigraphy of the Marine Pliocene and Pleistocene of San Pedro, California," *Mem. Calif. Acad. Sci.*, Vol. III (1903).

become current, and furthermore certain perplexing problems have arisen and still remain unsolved.

PREVIOUS WORK AND THE ANOMALY TO WHICH IT LED

In order to direct attention to these persistent problems it will be well to consider briefly Arnold's account of the geology of the island. Arnold reported 20 feet of unfossiliferous Miocene shales as the lowest beds exposed. These are tilted to the north and so appear only on the south end of the island. Upon these lie unconformably 45 feet of highly fossiliferous fine sands and clays, supposedly of late Pliocene age. This formation is also tilted to the north. It forms the main mass of the island. Arnold used the name San Diego formation for this deposit, but later J. P. Smith[1] named it the Santa Barbara. Upon these Santa Barbara beds lies unconformably a fossiliferous sandstone, 12 feet thick according to Arnold, but somewhat thicker by my own measurements. This was named the Lower San Pedro series by Arnold, who classified it as lower Pleistocene. Finally upon this lies unconformably a curious deposit of silt, cobbles, and coquina 10 feet thick. This was called by Arnold the Upper San Pedro series, and was regarded as of later Pleistocene age. Above this, and forming the flat top of the island, lies a thin veneer of earthy continental sediment similar to that which forms the surface layer of the terraces round San Pedro.

Arnold attempted both chronologic and climatic correlation of the faunas contained in these deposits. The climatic correlation was later made the subject of a broader and more exact investigation by Smith.[2] With regard to the Deadman's Island faunas Smith's and Arnold's results are essentially the same. Both these authors regarded the fauna of the Santa Barbara formation as one that flourished under a cool climate (according to Smith 12° F. colder than the present minimum temperature of San Pedro). The Lower San Pedro fauna was supposed to indicate an equally cold climate. The Upper San Pedro fauna, on the contrary, was held to be one that lived un-

[1] J. P. Smith, "Geologic Range of Miocene Invertebrate Fossils of California," *Proc. Calif. Acad. Sci.*, 4th Ser., Vol. III (1912).

[2] J. P. Smith, "Climatic Relations of the Tertiary and Quaternary Faunas of the California Region," *Proc. Calif. Acad. Sci.*, 4th Ser., Vol. IX (1919).

der a climate with a minimum temperature 4° F. warmer than the present temperature at the same locality.

It will be well at this point to acknowledge indebtedness to Arnold for his pioneer attempt at climatic correlation in this region, and still more so to Smith for his study of method. Smith correlated each fauna with climatic conditions by tracing the present-day distribution of a number of supposedly characteristic species. For instance the Santa Barbara formation on Deadman's Island had yielded:

Chlamys caurina Gould
Chlamys hericia Gould
Thyasira disjuncta Gabb
Chrysodomus tabulatus Baird
Argobuccinum oregonense Redfield
Panomya ampla Dall

These are distributed in the living fauna mainly to the north of San Pedro; some, *Chlamys caurina* for instance, are now limited within a range far north of San Pedro—between 800 and 2,000 miles. All this, of course, seemed to indicate the temperature conditions of the British Columbia coast, that is, 12° to 15° F. colder than San Pedro today. But the Deadman's Island faunas were large and contained many wide-ranging species. These were of course properly disregarded as having no great significance. But along with them were neglected some very important forms, for instance:

Pecten stearnsii Dall
Barbarofusus barbarensis Trask
Turritella cooperi Carpenter
Turritella jewetti Carpenter

None of these forms live at the present day with the cold-water species cited in the first list. Rather their main present distribution is to the south of San Pedro. *Pecten stearnsii*, though extinct, is a member of a group of *Pecten* s.s. which occurs only in warm waters, i.e., minimum temperature above 60° F. Now if any such climatic correlations can be trusted this evidence points to a warm climate. This was disregarded by Arnold and Smith whose conclusion that the climate of Santa Barbara time was cold seems accordingly to be extremely doubtful. Plainly considered, the evidence consists of two mutually contradictory parts. Neither Arnold nor Smith (nor subse-

quent workers) appears to have realized that one part of the evidence positively invalidates the other; that unless the two be in some way harmonized it is not possible to use either. Therefore, correlations of any sort based upon parts of such evidence are actually without basis. Furthermore, for similar reasons the same objection must be recognized to using indiscriminately the fossils of the Lower and Upper San Pedro formations, for both yield fossils which could not well have lived together.

PLAN OF WORK ON THE PROBLEM

It seemed desirable before proceeding further toward the solution of this problem to check the correctness of these anomalous occurrences. Accordingly the author and his students made their own collections from Deadman's Island. These yielded some unexpected facts, the finding of which is the principal reason for the appearance of this article. In the first place the Santa Barbara beds were found to be remarkably complicated. The fossils occur in six easily distinguished zones. One of these zones contains only cold-water species, and in most of the other zones either cold- or warm-water forms greatly predominate. This seemed to be leading to the conclusion that the anomaly was due to the failure, all too common in geological field work, of previous workers to make zonal collections. But it soon became clear that this was no solution of the main problem, for most of the zones of the Santa Barbara formation, also both Lower and Upper San Pedro formations, each of which consists of a single zone, contain an incongruous mixture of cold- and warm-water species.

A suggestion for the plan of attack on this problem came from an unexpected source. It has long been known that certain formations contain fossil faunas which are not of the same age as the formation which contains them but older, and *derived* from another deposit by erosion. In recent years S. S. Buckman has argued for the existence of *derived faunas* in the Jurassic of England. In the course of his work Buckman has developed the philosophy of this idea. He has shown plainly enough how stratigraphy may be complicated by the erosion of deposits and redeposition of their faunas. Such faunas indicate neither the age nor bionomic conditions of the

zones in which they occur. But they may be mixed with autochthonous fossils which, of course, do correctly indicate these things. This theory is not only specially applicable to the Deadman's Island cases, but in fact receives some confirmation therefrom. The difficulty with older faunas has been to demonstrate beyond all doubt that certain fossils in them are not autochthonous but derived. But in the Deadman's Island faunas this is quite obvious. Plainly, warm- and cold-water faunas of any one locality are not synchronous, though they occur in the same bed: the *climate* could not be warm and cold at the same time. One of them at least must be older than the deposit and *derived*. Further proof will be evident in the sequel, but it should be indicated here that the formal proving of this proposition has been subordinated to a further purpose, that of using this theory as a basis to work out a harmonious interpretation of the whole series of deposits.

Enough has been said to show that hitherto no very clear faunal analysis has been applied to these deposits. Too often attempts at faunal analysis resulting in the delimitation of narrow zones have met with adverse criticism and have even been depreciated on the grounds of being mere "hairsplitting." This is because many fail to realize that fine zoning is not mere splitting. Rather, it is the recognition and the separation of significant stratigraphic detail. On the contrary, the occlusion of separable zones, no matter how thin they may be, in one zone is confusion—a covering up of truth. These considerations made it seem desirable to attempt to discern the finest zonal subdivisions in these Deadman's Island strata, and are repeated here in justification of the plan of zones presented in this article.

DETAILED RESULTS

The Santa Barbara formation on Deadman's Island lies disconformably upon hard, highly calcareous shales which Arnold called Miocene. These have hitherto been supposed to be unfossiliferous, though, some fossils, notably foraminifera, are to be found in calcite-filled cracks in the shale, having fallen to that position from the overlying deposit. Recently, however, specimens of "*Plagiostoma*" *pedroana* Trask were obtained from the shale itself, a reward to the assiduous collecting of Miss Kathryn McGee. This is an important dis-

covery. It permits a tentative correlation of these shales with the formation which crops out along the coast from San Pedro to Point Fermin. These have been supposed to be of Miocene age, though it must be confessed there is very little reason for that correlation. The dating of these beds, and the estimation of the hiatus between them and the Santa Barbara formation, should be regarded as problems.

The lowest zone of the Santa Barbara beds is a layer of hard, calcareous shale with many fossils. It averages 6 inches thick. It contains waterworn cobbles of quartzite, diorite, and siliceous shale, the latter being similar to certain of the Miocene shales of Los Angeles County. These characters suggest at once a marine glacial deposit, but there are other interpretations. This may be a composite deposit, the cobbles belonging to an earlier sedimentation. The fossil fauna a partial list of which follows is important.

Foraminifera

Cassidulina reflexa Galloway and Wissler
Cassidulina californica Cushman and Hughes

Pelecypoda

O Nucula castrensis. Hinds
O Venericardia ventricosa Gould
O Phacoides acutilineatus Conrad

Gastropoda

Nf Chrysodomus tabulatus Baird
Sb Barbarofusus barbarensis Trask
Sb Turritella cooperi Carpenter

The abbreviatory symbols used with the names in this and other lists are intended to denote certain facts brought out in faunal analysis, and their significance, as follows:

N —now living mainly north of San Pedro and hence indicating a colder climate than that of San Pedro today.
S —now living mainly south of San Pedro.
E —extinct.
C —common.
R —rare.
X —apparently of restricted vertical range.
O —two valves of pelecypods still together as in life and hence indicating that the species is autochthonous.
● —shells filled with matrix of an older deposit and hence indicating that the species has been derived.

f—shells intact and fresh: a proof that they are autochthonous.
w—shells waveworn
b—shells in fragments } Proof that they have been derived.

In the faunal list above, the southern species give evidence in their worn and broken condition of having been derived from an earlier deposit, hence they are no evidence of the bionomic conditions under which zone No. 1 was formed. The northern species on the contrary are well preserved. Presumably they lived, died, and were buried while the deposit was accumulating. They would thus appear to indicate an age of cool climate. The multitude of individuals and profusion of species of the genus *Cassidulina* are entirely in accord with this conclusion. However, there is nothing in the fauna which would suggest as cold a climate as might be expected from the similarity of the deposit to a marine glacial boulder clay. But probably the temperature was somewhat below that of San Pedro today.

Lying upon zone No. 1 is a 6-inch layer of hard gray shale which weathers to a rusty yellow. This is zone No. 2. It contains only two species.

Pelecypoda
EXO Calyptogena gibbera Crickmay
CO Phacoides acutilineatus Conrad

The latter species is the more abundant. The shells are densely crowded though not upturned in any confusion. They are evenly distributed throughout the bed. They are obviously autochthonous, but unfortunately have no special climatic significance. The *Calyptogena* is peculiar to this zone and locality. It may later prove to be of more than usual value in correlation.

Upon zone No. 2 on the west side of the island lies zone No. 3, a deposit of fine yellow sand averaging 20 inches in thickness. On the east side of the island, on account of the failure of zones 1 and 2, zone 3 lies directly upon the Miocene(?) basement. In this zone the fossils are numerous but not crowded. They are evenly distributed through the bed. A partial faunal list follows:

Anthozoa
Caryophyllia californica Vaughan
Pelecypoda
O Nucula castrensis Hinds

EXO Pecten stearnsii Dall
N Chlamys jordani Arnold
N Chlamys hericia Gould
SO Venericardia barbarensis Stearns
O Venericardia ventricosa Gould
S Chama pellucida Sowerby
EO Macoma sp. nov. = M. calcarea, Arnold 1903

Gastropoda
SRF Cytharella branneri Arnold
CF Barbarofusus barbarensis Trask
Rf Epitonium indianorum Carpenter
SRf Trivia ritteri Raymond
Nb Argobuccinum oregonense Redfield
Cf Turritella cooperi Carpenter
R Turritella cf. jewetti Carpenter
Rf Astraea undosa Wood
f Calliostoma canaliculatum Martyn

All the fossils except the *Argobuccinum* are fresh in appearance. This is taken to mean that they are mostly autochthonous. If this be correct the presence of the *Barbarofusi*, the *Turritellae*, and certain Mexican species would indicate a warm climate, probably warmer than that of San Pedro today. It is significant that *Pecten stearnsii*, presumably a warm-water form though actually extinct, occurs with both valves together as in life. Obviously it is not derived. It therefore confirms the conclusion that zone 3 represents a time of warm climate. But the presence of the two northern species of *Chlamys*, apparently autochthonous, appears to be contradictory evidence. These species are represented by small shells similar to the stunted forms by which they are represented in the southern limit of their range in the living fauna, namely in deep water off San Diego. So the presence of these cool-water pectinidae is not necessarily contradictory evidence, but may lead to the further conclusion that zone 3 was deposited in water between 50 and 100 fathoms deep.

Zone 3 passes by gradual transition into zone 4, a deposit of very fine silt or clay densely charged with fossils. These fossils, mostly small, even microscopic, are extremely numerous, there being several million to the cubic foot. They are distributed patchily, though thickest in the middle part of the zone. This zone is 12 feet thick on the west side of the island, but thins down to 7 feet on the east

side where, for some unexplained reason, fossils are much scarcer. A partial list of fossils follows:

Foraminifera

f Lagena squamosa Montagu
f Quinqueloculina dutemplei d'Orbigny
f Triloculina trigonula Lamarck
f Triloculina insignis Brady
f Biloculina depressa d'Orbigny

Bryozoa

Cf Tubucellaria sp. nov.
R Tubucellaria punctulata Gabb and Horn
Cf Idmonea californica d'Orbigny
f Microporella heermani Gabb and Horn

Pelecypoda

EO Leda minuta var. praecursor Arnold
O Nucula castrensis Hinds
CNf Chlamys jordani Arnold
Nf Chlamys hindsii Carpenter
CNf Chlamys hericia Gould
CO Venericardia ventricosa Gould
Rf Milneria kelseyi Dall
Sf Chama pellucida Sowerby
Nf Thyasira gouldii Philippi
NO Cardium centifilosum Carpenter[1]
Nf Marcia kennerlyi (Carpenter) Reeve
Nf Marcia subdiaphana Carpenter
EO Macoma sp. nov. = M. calcarea, Arnold 1903

Gastropoda

Nf Chrysodomus tabulatus Baird
CNf Amphissa columbiana Dall
Nf Trophon multicostatus Eschscholtz
Nf Trophon macouni Dall
Nf Trophon stuarti Smith
Nf Trophon tenuisculptus Carpenter
Nf Argobuccinum oregonense Redfield
Sw Turritella cooperi Carpenter
Sf Turcica caffea Gabb

This is a complicated fauna. Unfortunately lack of space prevents a complete listing of it, but at least it may be summarized. It contains:

[1] This species, commonly referred to *Protocardia*, has no connection with that genus. It would seem to belong to an unnamed subgenus of *Cardium*.

Foraminifera, about 100 species, mostly Lagenidae and Miliolidae, families that favor warm waters, but also many others and among them many species of Cassidulina, a boreal genus.

Radiolaria, several species.

Sponge spicules, several species.

Bryozoa, about 4 species of cyclostomatous forms which are so abundant as to make up more than 50 per cent of the total weight of animal remains in the deposit; also a number of cheilostomes.

Mollusca, a large fauna, mostly northern species, many of which now range southward into the Californian province at least in deep water.

The whole fauna suggests deep water—100 fathoms or more perhaps. The mollusks with few exceptions suggest cold water but that appearance may be no more than the effect of depth. Too little is known of the ranges of the bryozoans to base any conclusion upon their occurrence. And the foraminifera offer incongruous evidence, some of them suggesting a warm climate, others a cold. All of them are very fresh; and it seems hardly possible that these delicate shells could survive any wave-wear, so presumably all are autochthonous. Hence a satisfactory interpretation is not possible. However, it is worth suggesting that a more protracted study of this rich fauna than the author has had time to make would yield great rewards.

Zone 4 is overlain by a deposit of fine yellow sand 40 feet thick, the base of which makes a sharp contact with the zone below. The lower 25 feet of this sand is zone 5. The upper 15 feet with many small concretions forms zone 6. In zone 5 the fossils are distributed evenly but very sparingly throughout, except for a 2-foot bed appearing on the east side of the island 8 feet above the base in which shells of *Thyasira disjuncta*, with the two valves still together, are densely crowded. Zone 5 yields the following fossils:

Pelecypoda

O Nucula castrensis Hinds
Nf Chlamys jordani Arnold
NO Chlamys caurina Gould
O Venericardia ventricosa Gould
NO Thyasira disjuncta Gabb
O Phacoides acutilineatus Conrad
NO Marcia subdiaphana Carpenter
NO Panomya ampla Dall

Gastropoda

Nf Chrysodomus tabulatus Baird

The evidence of this assemblage is unmistakable. This is the only decidedly cold-water fauna on Deadman's Island. J. P. Smith's estimate of a displacement of the isotherms of 1,500 miles, or a lowering of the temperature at San Pedro of 12°, originally adduced for the Santa Barbara and Lower San Pedro beds really applies only to this zone. Comparatively considered, this is a very great lowering of the temperature. Probably no greater occurred in any of the glacial stages. So, although this has always been regarded as a Pliocene deposit, there is hardly any doubt that it represents a glacial stage.

In zone 6 the fossils are sparingly and evenly distributed, except that they are somewhat more numerous in the uppermost 4 feet. The fauna is very different from that of the zone below.

Pelecypoda

CO Nucula castrensis Hinds
N Chlamys caurina Gould
O Venericardia barbarensis Stearns
CO Venericardia ventricosa Gould
CO Phacoides acutilineatus Conrad
NO Cardium centifilosum Carpenter
XECO Macoma sp. nov. = M. calcarea, Arnold 1903
CO Solen sicarius Gould

Gastropoda

w Olivella biplicata Sowerby
f Barbarofusus barbarensis Trask
f Alectrion perpinguis Hinds
N Amphissa columbiana Dall
Sf Epitonium indianorum Carpenter
SCf Turritella cooperi Carpenter
R Turritella cf. jewetti Carpenter

The reappearance of the genera, *Olivella*, *Barbarofusus*, and *Turritella* seems to mark a return to warm-water conditions after the cold climate of zone 5. Presumably the northern species in zone 6 have been derived. The fact that some have their valves together as in life is not necessarily proof to the contrary as may be seen from an examination of the details of zone 7.

The faunas of these six zones have long been regarded as belonging in the Pliocene. This conclusion, based originally on the finding of many supposedly extinct species in the desposits, no longer has its original force, for most of these species have since been found in the

living fauna. Only 5.5 per cent of the species are extinct. So it is quite reasonable to regard these as early Pleistocene faunas.

Overlying zone 6 with slight discordance is a deposit 20 feet thick of pale gray sandstone of much coarser grain than the subjacent deposits. Arnold, considering this equivalent to his Lower San Pedro series of the mainland, called it by that name. However, this correlation is open to question: both lithology and fossils at these two places are somewhat different. It seems better to refer to this bed on the island simply as zone 7. The fossils are very numerous but are confined to the lowest 5 feet or so of thickness. The fossil fauna is a large and varied one. Mollusks predominate. About 6 per cent of the species appear to be extinct, but some of these are derived fossils, so the correct percentage of extinct forms is somewhat less—about 4.5. A partial list of the fauna follows:

Pelecypoda

f Nucula castrensis Hinds
Sf Leda taphria Dall
NW Chlamys hericia Gould
Nb Chlamys caurina Gould
Sf Lima dehiscens Conrad
NO ● Thracia trapezoides Gabb
R Venericardia barbarensis Stearns
R Venericardia ventricosa Gould
NO ● Cardium centifilosum Carpenter
Sf Cardium quadragenarium Conrad
NO ● Cardium corbis Martyn
f Cardium californiense Deshayes
CO Phacoides acutilineatus Conrad
SCf Phacoides nuttallii Conrad
SCf Phacoides californicus Conrad
NO ● Marcia subdiaphana Carpenter
f Paphia staminea Conrad
f Saxidomus nuttallii Conrad
Rf Macoma secta Conrad
Cf Macoma nasuta Conrad
f Macoma inquinata var. arnheimi Dall
XEO ● Macoma sp. nov. = M. calcarea, Arnold 1903
f Mactra nasuta Gould
R Schizothaerus nuttallii Conrad

Gastropoda

Sf Conus californicus Hinds

REX Cymatosyrinx merriami Arnold
Clathrodrillia incisa var. ophioderma Dall
EX Borsonella hooveri Arnold
RS Cytharella branneri Arnold
Cf Olivella biplicata Sowerby
f Olivella boetica Carpenter
Rf Barbarofusus barbarensis Trask
SCf Barbarofusus arnoldi Cossmann
NRb Chrysodomus tabulatus Baird
Rb Alectrion fossatus Gould
Cf Alectrion mendicus Gould
Cf Alectrion cooperi Forbes
Cf Alectrion perpinguis Hinds
f Tritonalia barbarensis Gabb
RE Turbonilla arnoldi Dall and Bartsch
RE Turbonilla latifundia Dall and Bartsch
Nb Argobuccinum oregonense Redfield
Cf Turritella cooperi Carpenter
Cf Turritella jewetti Carpenter
Cb Turritella jewetti var. indet.
f Acmaea incessa Hinds
f Acmaea scabra Gould
f Calliostoma canaliculatum Martyn
Cw Tegula funebrale Adams

Scaphopoda

f Dentalium pretiosum Sowerby
f Dentalium neohexagonum Sharp and Pilsbry

This is a large and strangely mixed assemblage, but its interpretation is relatively simple. On the basis of the presence of such forms as *Chlamys caurina*, *Thracia trapezoides*, etc., Arnold and Smith regarded this as a cold-water fauna. Many of the shells of these species have the two valves together as in life. This is usually good evidence that the shells have never been reworked and so might be regarded as confirming the view of Arnold and Smith. But these species contain, between their valves, a matrix similar to that of zone 6 and utterly different from the deposit in which they now occur. This of course means that they have been derived from another formation. Besides this, many of these cold-water forms are wave-worn or in fragments. None show any valid evidence of being autochthonous. On the contrary the warm-water forms such as *Lima dehiscens*, *Cardium quadragenarium*, the *Conus*, *Cytharella*, and

Barbarofusi are remarkably fresh and perfectly preserved, and so are presumably autochthonous. The conclusion therefore is inevitable that this fauna represents a climate as warm or slightly warmer than that of San Pedro today. So the accepted and time-honored climatic interpretation of the fauna is without basis and must be discarded.

On the other hand, Arnold's opinion that the deposit was formed in shallow water seems good. The profusion of *Cardium* and other shallow-water types confirms the conclusion.

An extremely interesting detail is the abundant occurrence of *Cardium corbis* as a derived fossil—interesting, even remarkable, because it is unknown as an autochthonous fossil anywhere in the whole sequence of formations. There seem to be two possibilities. Either this species comes from some zone of the Santa Barbara formation which fails to appear on the island, perhaps a zone later than No. 6, or it may have come from the destruction of shallow-water equivalents of zone 5. It seems most likely that this species comes from the destruction of a cold-water zone that may be conjectured to have overlain zone 6. This would account the more readily for the presence in zone 7 of certain other derived fossils of doubtful origin, such as *Thracia trapezoides* and *Marcia subdiaphana*. Also it would explain why *Cardium corbis* does not appear among the derived fossils of zone 6.

Lying horizontally upon the beveled edge of zone 7 there is a curious deposit composed of shells most of which are greatly waveworn and broken, pebbles, and a matrix of fine silt. This is zone 8. The fossils and pebbles occur mainly in the lower 3 feet of the deposit in which they lie, in the utmost confusion, packed closely together with almost no matrix. This is not necessarily a beach deposit, for composite sediments of this sort may be formed even at considerable depths. The presence of pelecypod shells with the valves still together as in life seems to show that the deposit was formed below the field of strong-wave action. But some of the autochthonous fossils are shallow-water forms—*Paphia staminea* and the *Mytili*, for instance. These considerations seem to indicate that the deposit was formed under 10 to 20 fathoms of water.

The fauna is an extraordinary mixture:

Brachiopoda

R Terebratalia caurina Gould

Pelecypoda

Nucula castrensis Hinds
Glycymeris barbarensis Conrad
f Mytilus californianus Conrad
f Mytilus edulis Linne
Chlamys circularis Sowerby
R Hinnites giganteus Gray
RSf Crassinella branneri Arnold
Venericardia ventricosa Gould
RSf Cardium quadragenarium Conrad
CO Paphia staminea Conrad
O Petricola carditoides Conrad
Cf Tellina bodegensis Hinds
Sf Macoma secta Conrad
Macoma nasuta Conrad
Macoma inquinata var. arnheimi Dall
Ew Macoma sp. nov. = M. calcarea, Arnold 1903
SO Cumingia lamellosa Sowerby
C Spisula falcata Gould
C Schizothaerus nuttallii Conrad
Cryptomya californica Conrad
O Platyodon cancellatus Conrad
O Zirphaea gabbi Tryon
O Pholadidea penita Conrad

Gastropoda

SCf Conus californicus Hinds
Nf Cryptoconus carpenterianus Gabb
Antiplanes perversa Gabb
Borsonella bartschi Arnold
C Olivella biplicata Sowerby
C Olivella boetica Carpenter
Rb Strigatella idae Melvill
Rb Barbarofusus traski Dall
R Barbarofusus monksae Dall
R Barbarofusus luteopictus Dall
ER Pisania fortis Carpenter
NRb Chrysodomus tabulatus Baird
C Alectrion mendicus Gould
C Alectrion perpinguis Hinds
C Alectrion cooperi Forbes
Alectrion fossatus Gould
w Amphissa columbiana Dall
Nf Tritonalia lurida var. aspera Baird
E Tritonalia keepi Arnold

Sf Tritonalia poulsoni Carpenter
f Acanthina spirata Blainville
Nw Thais lamellosa Gmelin
Rw Trophon pacificus Dall
Rf Epitonium indianorum Carpenter
R Turbonilla latifundia Dall and Bartsch
Sb Bursa californica Hinds
NRb Argobuccinum oregonense Redfield
Bittium asperum Gabb
f Turritella cooperi Carpenter
Sf Polinices recluziana Deshayes
Nb Polinices lewisii Gould
Calliostoma canaliculatum Martyn
SR Haliotis fulgens Philippi

Less than 3 per cent of this fauna appear to be extinct. But no very exact interpretation can be made of these percentages—they depend on too many incalculable factors. About 95 per cent of the specimens are waveworn or broken. All the northern species are in this condition: many of the southern are. So only a small fraction of the fauna is autochthonous. This fraction consists only of species now living off San Pedro. So there is nothing in the fauna of zone 8 to warrant giving it the interpretation that J. P. Smith made of the fauna of the Upper San Pedro in general, namely, that it represents a temperature 4° warmer than that of San Pedro today.

GENERAL CONCLUSIONS

The tabular summary of the stratigraphy and its interpretation (see p. 634) will be found useful as it brings the main results within the compass of a single page, thus allowing the whole to be viewed at a glance, and the various parts the more readily to be compared. This summary shows plainly that stratigraphically the Deadman's Island column is amazingly incomplete: the gaps in the record represent much more time than the actual sediments. The faunas certainly represent parts of a number of climatic fluctuations, but the incompleteness of the representation is too great to make out any continuous plan of climatic changes. Also the exactness of the temperature figures is at best doubtful, because it depends upon the rather uncertain process of evaluating the effect on the faunas of changes in the depth of the water. Moreover, there is no way of

estimating how many fluctuations passed without sedimentary record between such zones as 6 and 7, or 7 and 8. The whole thing is complicated by the effects of diastrophism. To this is probably due the strange circumstance that only one climatic extreme, and that one of cold climate, is represented in the record—zone 5. This is, of course, the opposite of what is to be expected, because the epochs of cold climate should be accompanied by increased wave erosion, and in consequence failure of sediment to accumulate except in very deep water.[1] After these remarks it should hardly be necessary to sum up by saying that this sedimentary record, though it consists of mere vestiges, bears witness to a history of the deepest intricacy.

This study may seem to have introduced an unduly complicated zonal arrangement, and thereby made correlation correspondingly difficult. This suggestion is one that will appeal to many because fine subdivision is not high in popular esteem, but it is one that would come only from an incomplete perception of the problem. For such difficulties as there may be exist already, and are merely exposed by work of this sort. Furthermore, the account of the stratigraphy is merely a report of facts, and any attempt in this case to make the zonal arrangement less complicated would be simply an obscuring of part of the evidence—a falsification of the story. Finally, a cogent reason for reporting all possible detail is that while this study was in progress steam-shovels and excavating dredges were at work on the island in an attempt to improve Los Angeles harbor. By the time this article appears in print Deadman's Island will have been razed; its superb fossil beds and beautiful stratal succession will be no more. But the loss is more than merely that of a fine example for stratigraphy. This, like every stratigraphic section, was unique. Other sections may tell a similar tale, and may supplement the story with their own peculiar details, but no other will ever yield exactly the same record as that of Deadman's Island.

THE BEARING OF THESE RESULTS ON CORRELATION OF THE CENOZOIC

The writer has made no attempt to correlate his zones with their stratigraphic equivalents at other places chiefly because of the lack

[1] On the basis of the solar cyclonic hypothesis.

of similarly detailed studies elsewhere. This is a problem for future work. However, some suggestions may be made regarding it. The

TABLE I

SUMMARY

Age	Formation Name	Zone	Fauna	Lithology	Thickness	Relationship with Bed Below	Mean Annual Temp.
Pleistocene	Upper San Pedro	8	†Paphia staminea *Haliotis fulgens, Pisania fortis	Coquina and cobbles, matrix of silt	8 feet	Unconformity	63° F.
	Lower San Pedro	7	†Phacoides acutilineatus †Barbarofusus arnoldi *Cymatosyrinx merriami	Sandstone	20 feet	Unconformity	63° F.
	Santa Barbara	6	†Venericardia barbarensis †Barbarofusus barbarensis	Fine sand with concretions	15 feet	Conformity	63° F.
		5	†*Chlamys caurina †*Thyasira disjuncta	Fine sand	25 feet	Disconformity	50° F.
		4	†Cardium centifilosum †Chlamys hericia †*Miliolidae & Bryozoa	Clay	12 feet	Conformity	?
		3	†Barbarofusus barbarensis *Pecten stearnsii	Fine sand	1½ feet	Disconformity	63° F.
		2	†Phacoides acutilineatus *Calyptogena gibbera	Shale	½ foot	Conformity	?
		1	Chrysodomus tabulatus †Cassidulina spp.	Shale	½ foot	Unconformity	55° F.
Miocene?	?	...	Pseudamusium pedroanum (Trask)	Shale	? 20 feet exposed		?

* Characteristic species or guide-fossils.
† Dominant species.

first difficulty in the way of correlation is the possibility of the presence of derived fossils. These may lead one far wide of the mark in correlation, but they may generally be detected by a careful faunal analysis. Such analysis was plainly needful in dealing with the Dead-

man's Island faunas. It brought out the fact that in each zone either the cold- or the warm-water species had been derived. In this connection it is interesting to notice that some zones, No. 7 for instance, contain worn specimens of cold- and warm-water species. Both have been derived, but one (in zone 7 warm water forms such as *Turritella jewetti*) give evidence in their worn and decayed condition of more than one "derivation" and redeposition. On the other hand, there are certain species, e.g., *Nucula castrensis*, *Venericardia ventricosa*, and *Phacoides acutilineatus*, which appear as autochthonous fossils in almost every zone, both cold and warm. But this is no argument against the effect of climate on the fauna for these species have so broad a range that none of the Pleistocene climatic extremes was sufficient to drive them out of the latitude of San Pedro. Moreover, their presence shows that physical conditions during the formation of most of these zones were such as to allow pelecypods to be buried with the two valves together as in life. And hence that one of the main postulates of this research is reasonably sound. Furthermore, analysis is obviously advantageous because it brings out the meaning of evidence which is too complex to interpret at a glance. It is proper to suggest that some other Californian faunas might yield something unexpected if treated in this way. Perhaps an explanation might be got of the anomalous ranges of certain Miocene and Pliocene species.

Another common obstacle is the lack of correspondence between faunal and stratal development, that is, the period of time during which a deposit accumulated is rarely if ever coincident in its limits with the duration of the existence of the species or fauna. This principle is well enough known but is very commonly ignored. To ignore it in anything but the roughest correlation is to fall into almost certain error. Even in a single section this may cause trouble, for lithology being obvious is apt to mask the less obvious faunal changes. This may not seem a very formidable difficulty, but witness the fact that for years it has prevented collectors from noting the details of the occurrence of species in the Deadman's Island succession, and this in spite of the circumstance that each fossil fauna occurs in beds of a peculiar lithology. But especially for correlation over more than 2 or 3 degrees of latitude this principle is very important. This is

because the faunas may maintain their characters longer than the short period of time represented by local zones, long enough in fact for them to accomplish very considerable migrations such as might be induced by changes of climate. For, along with other phases of development, these faunas have been driven up and down the Pacific Coast of North America many times by the fluctuations of climate during the latest part of geologic time. As a result of this we may have highly similar faunas in California and British Columbia not synchronous, but successive. For instance, a fauna in the northern region similar to that of zone 5 might be synchronous with zones 3 or 6, but not with zone 5. One synchronous with zone 5 would, in the northern region, have an Arctic character. Ordinary principles of correlation would thus lead us to regard the fauna of zone 5 as synchronous with earlier or later faunas in the British Columbia region. But the fallacy and the means of guarding against it are obvious. Correlation under these circumstances, however, is anything but obvious. For this reason it is very desirable, if we are ever to work out any system in our late Cenozoic, to have accurate studies of contemporary faunas from as many stations as possible along the whole coast. When viewed in this light, the Pliocene and Pleistocene deposits and faunas of the north Pacific region take on a new importance. They should not be regarded, as they commonly are, as mere films of sediment unworthy of being called geologic formations, and containing fossil remains of extant and therefore uninteresting species. Rather they are vitally important records of a part of geologic time of which the sedimentary record is woefully scanty and meager.

But there are two other great difficulties in the way of correlation. The first of these is the lateral failure of zones, as a result of which a pair of neighboring sections of contemporaneous deposits may not possess a single zone in common, the zones in each section corresponding to the hiatuses in the other. This is the reason for the difference between the Pleistocene of Deadman's Island and that of San Pedro only a mile away, and of other places not much farther distant. The correlation of sections of this sort requires an attack from several angles. Lack of space precludes a full discussion, but it may be mentioned that the derived fossils may afford valuable clues, for they are the vestiges of the faunas of zones that have been de-

stroyed by penecontemporaneous erosion. It is therefore important in collecting fossils to take not only good specimens but the merest fragments also, for some species may be represented only by small fragments. For instance, the author has examined about 15,000 specimens from zone 8, and among them the species *Chrysodomus tabulatus* was represented by two pieces of less than half a whorl.

The second of these main difficulties is the persistence of nearly all the main elements of the faunas. This is a real difficulty, but an escape from it lies in the appreciation and accurate recognition of the few forms of restricted vertical range. Even this may not effect the desired result, for the application of this principle may not permit of establishing more than the contemporaneity of deposits, and the aim of correlation is the determination of synchronism. This aim is especially important in dealing with Pleistocene deposits because of the problem of correlating rather rapid climatic and diastrophic fluctuations with a standard chronology. In attempts at determination of synchronism the value of the finest zonal subdivision appears. For, when a sufficiently *complete* understanding of several sections and the history they represent is obtained, it then becomes possible to correlate on the basis of similarity in the succession of geologic events in various stratigraphic sections. And this does not mean a rough similarity of the sort that appears to have suggested the correlations advanced by Eaton in a recent article.[1] Eaton's surprising correlations, made without any clear statement of evidence, are certainly not of the sort to inspire confidence. The attempt to set Pleistocene events suddenly into a complete orderly history is apt to be a futile one. Before a chronologized history of the latest part of geologic time can be written, detailed studies of many sedimentary successions and their faunas are necessary. And equally essential is demonstrable correlation of depositional and erosional events with each other and with a standard chronology.

The reasons for the baffling nature of the stratigraphy of these Deadman's Island and other late Cenozoic deposits of the region is probably to be sought in the nature of the region itself. Since the Mesozoic no part of the Cordilleran belt of North America has be-

[1] J. E. Eaton, "Divisions and Duration of the Pleistocene in Southern California," *Bull. Am. Assoc. Petrol. Geol.* Vol. XII (1928).

haved like a geosyncline. What have been mistaken for geosynclines are in truth intermontane basins. The Cenozoic sediments were deposited partly in these basins, some above and some below sea-level, and partly on the continental shelf. Diastrophic modification of the basins and shelf produced both contraction and fragmentation so that toward the end of the Cenozoic only small basins remained. At the same time orogeny, approaching culmination, was more active and spasmodic, and so served to produce vertical fluctuations of the base-level of erosion of a violent sort unknown in geosynclines. In such a region of growing mountains base-level is rarely above the surface, even though the surface be low or inundated by sea water. Consequently, under these conditions sedimentary deposits form at various places unsynchronously and only at widely separated intervals of time. Such deposits will consist largely of reworked materials of the evanescent sediments accumulated during favorable fluctuations of base-level induced by a vacillating diastrophism and a changing climate. The actual deposits preserved will represent but fractions of the history of their times. Such deposits are the Deadman's Island formations. Indeed, such are the whole Pliocene and Pleistocene of California.

STRATIGRAPHY OF THE DECORAH FORMATION[1]

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ABSTRACT

The Decorah formation of Ordovician age has been defined as a shale lying above the Platteville limestone and below the Galena limestone at Decorah, Iowa. Lithologic sections show a gradation of the sediments from limestone and dolomite in southwestern Wisconsin to clastic shales in northern Iowa and Minnesota. The fauna of the formation warrants its correlation with the uppermost Black River and lowermost Trenton of the eastern standard section.

INTRODUCTION

In northeastern Iowa and adjacent parts of Minnesota and Wisconsin, there occurs a shale of Ordovician age that has been known as the "Decorah shale," with the type locality at Decorah, Winneshiek County, Iowa. This shale contains innumerable fossils and is particularly rich in species of bryozoans, brachiopods, and ostracods. Equivalent beds of limestone farther to the southeast are little less fossiliferous. Though the fauna has been well described, particularly in Minnesota, there has been a diversity of opinion with respect to the precise correlation of the formation.

It is the purpose in this paper to trace the changing lithology of the Decorah formation from the dolomitized limestone facies near Dubuque, Iowa, to the shaly facies at the north border of the state of Iowa; and to list faunules from the formation and show that they evidence a correlation of the Decorah with the uppermost Black River and lowermost Trenton formations in other regions. The details of the lithology and the systematic paleontology of the formation are being prepared.

Field work.—This paper is based on field work carried forward during parts of each summer from 1924 to 1928, for the most part in the type region, but partly in Missouri, Ontario, and New York. Work in the office has continued through the intervening periods.

Acknowledgments.—The writer wishes to acknowledge his indebtedness to Dr. A. O. Thomas, who has supervised the field work, and to Dr. J. J. Galloway and Dr. H. N. Coryell for their counsel. The suggestions and criticisms of Dr. E. O. Ulrich, Professor R. S.

[1] Published with the permission of the Director of the Iowa Geological Survey.

Bassler, the late Professor Stuart Weller, and Dr. Percy Raymond have been appreciated.

DEFINITION OF THE DECORAH FORMATION

The name "Decorah" was applied by Calvin[1] to "the persistent body of shale between the two parts of what generally has been called the 'Trenton limestone'—from the city in which it is typically developed." This "shaly member of the Platteville stage ranges from twenty-five to thirty feet in thickness; it is everywhere very calcareous, with numerous bands and nodules of limestones distributed through it." Only one section is described in Calvin's report, that at the Dugway, along the Upper Iowa River at the west end of Main Street, Decorah: "Practically the whole thickness of the beds is here shown. The deposit is more argillaceous toward the base of the section, and becomes quite calcareous toward the top." The term "Decorah formation" has been and should be applied not only to the "persistent body of shale" at the type locality but to any beds in the region that are of the same age as the shale beds, regardless of their lithology.

The Decorah formation has been described briefly by those who have written on the areal geology of the region. The earliest workers did little more than make casual references to the beds, and it was not until the Iowa Geological Survey began the publication of county reports that good descriptions of the beds in Iowa were made available. Calvin[2] described the lithology of that part of the Ordovician that he later named "Decorah," and undertook to trace the continuity and equivalency of the beds. In addition to the county reports prepared by Calvin, the report on Clayton County by Leonard[3] and two of the folios of the United States Geological Survey[4] contain descriptions of the formation. The best résu-

[1] Samuel Calvin, "Geology of Winneshiek County," *Iowa Geol. Survey*, Vol. XVI (1907), p. 61.

[2] Samuel Calvin, "Geology of Allamakee County," *ibid.*, Vol. IV (1895), p. 36; Samuel Calvin and H. F. Bain, "Geology of Dubuque County," *ibid.*, Vol. X (1901), p. 381; Samuel Calvin, "Geology of Winneshiek County," *ibid.*, Vol. XVI (1907), p. 43.

[3] A. G. Leonard, "Geology of Clayton County," *ibid.*, Vol. XVI (1907), p. 213.

[4] U. S. Grant and E. F. Burchard, "Lancaster–Mineral Point Folio," *U.S. Geol. Survey Geol. Atlas, No. 145* (1907); E. W. Shaw and A. C. Trowbridge, "Galena-Elizabeth Folio," *ibid., No. 201* (1916); *Illinois Geol. Survey Bull. 26* (1916).

mé of the lithology of the beds in Iowa has been published by Sardeson.[1]

The classification of the beds of Decorah age in Minnesota had progressed nearly to completion before the work in Iowa was initiated. The Minnesota stratigraphy has been summarized by Winchell and Ulrich.[2]

Many geologists have expressed opinions with regard to the age of the Decorah formation; their judgments differ.

Location of outcrop.—The Decorah formation crops out in a narrow belt extending west of the Mississippi River from St. Paul, Minnesota, to Dubuque, Iowa. In Minnesota the outcrop passes southeastward from St. Paul through Dakota, Rice, Goodhue, Dodge, Olmstead, and Fillmore counties to the state line near Mabel, Minnesota. From Minnesota the outcrop crosses to Hesper, on the north line of Winneshiek County, Iowa, and extends diagonally across Winneshiek and Allamakee counties to the Mississippi River at McGregor, in the northeast corner of Clayton County; thence it continues along the river bluff as far southeast as Dubuque, at which place it dips below the river. Equivalent beds continue in Grant County, Wisconsin, and extend into a very small area along the Galena River in northern Jo Daviess County, Illinois.

FIG. 1.—Map of the outcrop of the Decorah formation in Iowa.

Divisions of the Decorah formation.—In discussing in detail any

[1] F. W. Sardeson, "The Galena Series," *Bull. Geol. Soc. Amer.*, Vol. XVIII (1907), p. 179.

[2] N. H. Winchell, and E. O. Ulrich, "Lower Silurian Deposits of the Upper Mississippi Province," *Geology of Minnesota*, Vol. III, Part II, *Geol. Nat. Hist. Survey Minnesota* (1897), p. lxxxiii.

considerable thickness of rocks, it is not only convenient but necessary that one adopt smaller units than the formations. Thus the Decorah beds in Minnesota have been divided into several faunal zones. The use of fossil names for divisions is less satisfactory than the use of place names, because one infers that the range of the fossil is constant, and does not consider that the facies or ecological conditions may have affected the faunas of the time, so that the guide or index fossil of the zone may be lacking. But with a place name for a division, one can refer to the member any beds equivalent in age to those at a type section, without regard to the presence or absence of a particular fossil or lithology. Inasmuch as the Decorah formation is readily divisible into three distinctive lithologic units in the middle part of its Iowa outcrop, three members have been designated, with type localities at Spechts Ferry, Guttenberg, and Ion, respectively.[1]

Comparison with Minnesota section.—Inasmuch as the members of the Decorah formation in Iowa are continuous and identical with the faunal zones in Minnesota, the two will be compared. The most recent discussion of the Minnesota classification is that of Bassler,[2] who gives the following classification, which is essentially that of the old Geological and Natural History Survey of Minnesota:

Stewartville dolomite
Prosser limestone
Decorah shale { Fucoid bed; Chasmatopora bed; Ctenodonta bed; Rhinidictya bed; Stictoporella bed }
Platteville limestone

"In northern Iowa a shaly gray limestone filled with a variety of *Prasopora insularis*" forms the top of the Decorah shale; "the Fucoid bed closes the Black River in Minnesota." The Prasopora zonule is at the top of the Ion member in Iowa. The Ctenodonta bed is the equivalent of the Guttenberg member. The fucoids so characteristic of the Fucoid bed in Minnesota have not been recognized in

[1] G. M. Kay, "Divisions of the Decorah Formation," *Science*, N.S., Vol. LXVII (1928), p. 16.

[2] R. S. Bassler, "Early Paleozoic Bryozoa of the Baltic Provinces," *U.S. National Museum, Bull. 77* (1911), p. 27.

Iowa, and thus it would seem that most of the Ion is to be identified with the Chasmatopora bed; the relatively unfossiliferous upper part of the Ion member may be, however, the correlative of the Fucoid bed.

The Spechts Ferry member includes beds continuous with the Stictoporella and Rhinidictya beds. The fauna of the former bed has been recognized in few sections in Iowa, and the bed is seemingly poorly developed.

Table I gives a comparison of the Iowa and Minnesota classifications of the Decorah beds.

The names "Platteville" and "Galena".—It is necessary that one explain the use of the names "Platteville" and "Galena" in Iowa

TABLE I

Classification in Iowa		Classification in Minnesota	
Lower GALENA or PROSSER formation		Clitambonites bed	PROSSER formation
DECORAH formation	Ion member	Fucoid bed Chasmatopora bed	DECORAH formation
	Guttenberg member	Ctenodonta bed	
	Spechts Ferry member	Rhinidictya bed Stictoporella bed	
PLATTEVILLE formation		PLATTEVILLE formation	

and Minnesota. In Illinois and southwestern Wisconsin, the term "Platteville" should be used as defined[1] at the type locality, Platteville, Wisconsin. The overlying beds were designated the "Galena" by Foster and Whitney.[2] Thus the Mohawkian in southwestern Wisconsin has a twofold division by designation.

Because of changes in lithology, a threefold division is more convenient to use in Iowa and Minnesota. The "Platteville" limestone of Iowa does not include the uppermost beds of the typical Platteville of southwestern Wisconsin; these beds constitute the Spechts Ferry member of the Decorah formation in Iowa. More-

[1] H. F. Bain, "Zinc and Lead Deposits in Northwestern Illinois," *U.S. Geol. Survey, Bull. 246* (1905), p. 18.

[2] J. W. Foster and J. D. Whitney, "Geol. Lake Superior Land District," Part II, "The Iron Region," *U.S. 32d Congress, Spec. Session*, Vol. III, Exec. Doc. 4 (1851), p. 146.

over, the "Galena" formation in Iowa lacks the lower members of the Galena of the type region; the Guttenberg limestone is the base of the Galena formation of the type region. It is of advantage to continue the use of the name "Decorah" for a formation that in Iowa and Minnesota is a distinctive lithologic unit, and to restrict the terms "Platteville" and "Galena" in those states to include the beds below the Decorah and above the Decorah, respectively.

LITHOLOGY

The changing lithology of the Decorah formation can be seen in a series of sections from Platteville, Wisconsin, through Spechts Ferry, Guttenberg, and Ion to east of Decorah, in Iowa.

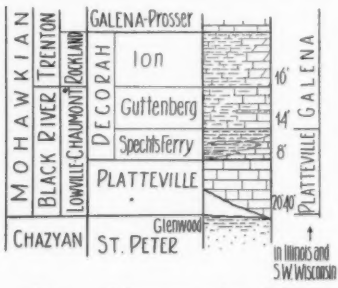

FIG. 2.—Columnar section of the Decorah and adjacent formations in northeastern Iowa, with classification of Illinois and southwestern Wisconsin on the right. The Chaumont formation, new name, is discussed on p. 664.

Section near Platteville, Wisconsin.—In the type region of the Platteville formation in southwestern Wisconsin and in northwestern Illinois, the Spechts Ferry member becomes the top member of the Platteville formation, inasmuch as the Decorah formation is not recognized in that region. The top of the Platteville consists of the "glass rock" and an overlying shale; the "glass rock" is possibly older than the base of the typical Spechts Ferry, and it is referred questionably to that member. The Guttenberg member is described locally as the "oil-rock member" or "brown rock"; the Ion includes the lowest Galena dolomites. A typical section of the beds of Decorah age is exposed in a ravine in the center of the northwest quarter of Sec. 20, T. 3 N., R. 1 W. (Platteville Township, Grant County), about 2 miles west of Platteville, Wisconsin. At this section, the dolomite of the Galena formation grades into the brownish, crystalline dolomite, and dolomitic shale beds of the Ion member without perceptible change. The Guttenberg member, 11 feet thick, is composed of undulating 1–3 inch beds of brownish, fine-textured, hard, somewhat laminated limestone, many beds of which are very

fossiliferous; with a few intercalated thin beds of chocolate-brown, fine-textured, laminated, brittle, non-argillaceous shale that burns readily with a petroliferous odor—strictly speaking, the "oil rock." Table II gives the lithology for the Specht's Ferry member.

As one proceeds westward to the type section of the Specht's Ferry member, in the ravine along the roadside southwest of the C. M. St. P. and P. railroad station of Specht's Ferry, in the north-

TABLE II

SECTION OF SPECHTS FERRY MEMBER 2 MILES WEST OF PLATTEVILLE, WISCONSIN

	Thickness of Bed	From Top to Base of the Member
PLATTEVILLE formation (Decorah age):		
Specht's Ferry member:		
Bluish-gray, fine-textured, hard, massive limestone with black pyritic nodules and minute gastropods.....	5″	8′4″
Several beds of limestone of varying lithology, intercalated with beds of blue-green, laminated, jointed shale.....	4′2″	7′11″
The "glass rock"—dark-gray, fine-textured, very hard, brittle and tough, plane-bedded, non-laminated limestone, breaking conchoidally, splintering, resonant when struck; containing a few extremely well-preserved brachiopods, and trilobites and ostracods, in a bed a little more than a foot from the base (faunule listed on p. 657); beds 1½–9 inches in thickness, thin-bedded at base	3′4″	3′9″
Black, thin-bedded, finely-laminated, brittle shale	5″	5″
PLATTEVILLE limestone:		
Grayish, medium-textured limestone with undulating upper surface		

west quarter of Sec. 4, T. 90 N., R. 2 E. (Peru Township, Dubuque County, Iowa), true "glass-rock" beds are not present in the base of the Specht's Ferry member, though there are conspicuous limestones. There is no evidence to prove that these limestones are the same, and it is possible that they are younger than the "glass rock" and that those beds are absent at Specht's Ferry. The upper members of the Decorah formation are much the same as at Platteville. The base of the formation is at 670 feet A. T., 54 feet above the railroad tracks at the station. See Table III.

In a section in and above the quarry southeast of the railroad station at Specht's Ferry, the limestones of the Ion member have not

TABLE III

TYPE SECTION OF SPECHTS FERRY MEMBER IN RAVINE NEAR RAILROAD STATION, SPECHTS FERRY, IOWA

	FROM TOP OF BED TO—	
	Base of the Member	Base of Spechts Ferry
DECORAH formation:		
Ion member:		
Beds of brown, coarse-textured, earthy dolomite, and plastic, gritty, dolomitic shale		
Guttenberg member:		
Undulating 2- and 3-inch beds of brownish, fine-textured, fossiliferous limestone, with a few intercalated beds of "oil-rock" shale, and darker, coarse-textured limestone at the very top	12′ 0″	21′ 6″
Spechts Ferry member:		
Two beds, the lower 6 inches thick, of homogeneous grayish, fine-textured limestone containing pyritic nodules; forming a ledge over which the stream falls	10″	8′ 6″
Greenish-blue, laminated, plastic, argillaceous shales, highly fossiliferous, the fossils calcareous, *Homotrypa minnesotensis* a common species	2″	7′ 8″
Bed of blue, hard, brittle, highly fossiliferous calcareous shale	½″	7′ 6″
Bluish-green, laminated, argillaceous shale	6½″	7′ 5½″
Bluish, very calcareous, somewhat argillaceous, highly fossiliferous shale, containing many specimens of *Pionodema subaequata*	2″	6′11″
Bluish-green, laminated, argillaceous shale	9″	6′ 9″
Single bed of limestone of two lithologies; upper half of gray, hard, fine-textured, non-pyritic, unfossiliferous limestone; the lower of bluish, coarse-textured, laminated, highly fossiliferous, argillaceous limestone	3″	6′ 0″
Beds of dark blue-green to blue-gray, fine-textured, homogeneous, bedded, somewhat brittle, argillaceous shale with four intercalated beds of gray-blue, fine-textured, soft, somewhat fossiliferous limestone, from 1 to 4 inches in thickness	3′10″	5′ 9″
Rather soft, gray, fine-textured, homogeneous limestone having an undulating upper surface	4–8″	1′11″
Blue-green, argillaceous shale	2″	1′ 3″
Gray, fine-textured, hard, brittle limestone of irregular thickness	1–3″	1′ 1″
Somewhat lenticular beds of gray-blue, hard, brittle shale, the upper part fossiliferous, some parts mottled in color	2–4″	10″
Massive, homogeneous beds of gray, fine-textured limestone	3½″	6″
Black, hard, brittle, finely-laminated shale with calcareous fossils on bedding planes	2–2½″	2½″
PLATTEVILLE limestone:		
Twelve-inch bed of gray, fine-textured, hard, brittle, sparsely fossiliferous limestone, the upper surface of which is pitted and the upper part structurally shaly		

been dolomitized to as great a depth as in the ravine section a quarter of a mile away. As a result, the dolomites begin 32 feet 8 inches

FIG. 3.—East face of the quarry southeast of the railroad station at Specht's Ferry, Dubuque County, Iowa. The base of the Specht's Ferry member is at the top of the heavy ledge in the middle of the quarry face; the member includes the overlying shales; the top is an 8-inch bed of limestone immediately overlying the shales.

above the base of the formation. The uppermost non-dolomitic beds, 2 feet 2 inches in thickness, are of purplish, coarse-textured, crystalline limestone containing *Glyptorthis bellarugosa* and *Dalma-*

nella rogata intercalated with beds of greenish, calcareous shale and argillaceous limestone. The top of the Guttenberg member is 21 feet 6 inches above the base of the Spechts Ferry member.

TABLE IV

TYPE SECTION OF GUTTENBERG MEMBER IN RAVINE A MILE NORTH OF GUTTENBERG, IOWA

	Thickness of Bed	From Top of Bed to—	
		Base of the Member	Base of Spechts Ferry
ALENA formation:			
Prosser limestone:			
Heavy beds of light gray, fine-textured, fossiliferous limestone			
ECORAH formation:			
Ion member:			
Greenish, highly calcareous, somewhat fossiliferous, argillaceous shale with intercalated argillaceous limestone	1′ 0″	14′ 8″	37′11″
Gray to gray-blue, medium-textured, somewhat argillaceous, sparsely fossiliferous limestone	2′ 6″	13′ 8″	36′11″
Thin beds of grayish, medium-textured, argillaceous limestone and calcareous shale, some of the lower beds containing *Glyptorthis bellarugosa* and *Dalmanella rogata*	10′11″	11′ 2″	34′ 5″
Greenish, laminated, calcareous, argillaceous shale	3″	3″	23′ 6″
Guttenberg member:			
Purplish to brownish, coarse-textured, fossiliferous limestone in 2-inch beds	4′ 6″	15′11″	23′ 3″
Brownish, fine-textured, somewhat fossiliferous limestone	1′ 6″	11′ 5″	18′ 9″
Irregular and undulating bed of dark-brownish, fine-textured, brittle, non-argillaceous, bituminous "oil-rock" shale	1″	9′11″	17′ 3″
Two- to 4-inch undulating beds of brown, fine-textured, hard limestone; some beds highly fossiliferous, others relatively barren	9′ 5″	9′10″	17′ 2″
Blue-green, laminated, argillaceous shale	5″	5″	7′ 9″
Spechts Ferry member:			
Bluish, medium-textured limestone bed	5½″	.....	7′ 4″

At Guttenberg, the Decorah has not been dolomitized, and its three members are lithologically distinct; the Ion is more argillaceous than at Spechts Ferry; the Spechts Ferry and Guttenberg are of limestone and shale, respectively. The upper members are well exposed in the small ravine above the spring at the point where

Federal Highway 55 leaves the Mississippi River flood plain a mile north of Guttenberg, in the southwest quarter of Sec. 5, T. 92 N., R. 2 W. (Jefferson Township, Clayton County, Iowa), the type sec-

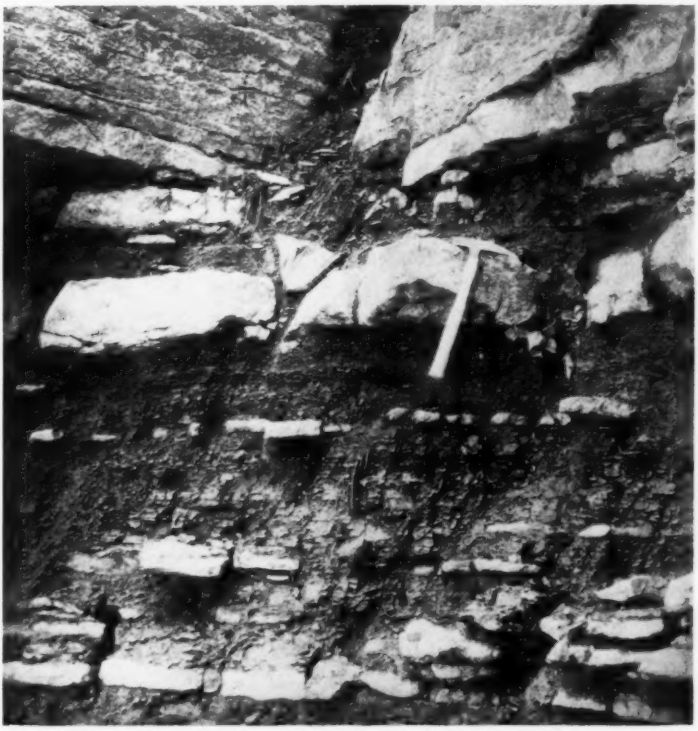

FIG. 4.—The contact of the Spechts Ferry and Guttenberg members of the Decorah formation in a small quarry in the northwest corner of the town of Guttenberg, Clayton County, Iowa. The hammer lies on the limestone bed that is the top of Spechts Ferry member.

tion of the Guttenberg member. The base of the Guttenberg member is 115 feet above the railroad tracks, at about 750 feet A. T.

There is a good exposure of the Spechts Ferry member at its contact with the Guttenberg member in a small quarry in the northwest corner of the city of Guttenberg, in the northwest quarter of

Sec. 8, T. 92 N., R. 2 W. The lithology of the Spechts Ferry member is not unlike that at its type locality; the member is 7 feet 4 inches thick.

TABLE V

SECTION AT TYPE LOCALITY OF ION MEMBER, SOUTHWEST OF ION, ALLAMAKEE COUNTY, IOWA

	Thickness of Bed	From Top of Bed to—	
		Base of the Member	Base of Spechts Ferry
GALENA formation:			
Prosser limestone:			
Heavy beds of light-gray, fine-textured, rather pure, sparsely fossiliferous limestone			
DECORAH formation:			
Ion member:			
Yellow-green, slightly calcareous, fossiliferous, bedded shale	4″	15′ 9″	37′ 8″
Beds of structurally shaly, blue-green, very argillaceous, fossiliferous limestone with occasional heavier, less argillaceous beds	6′ 8″	15′ 5″	37′ 4″
Green, laminated, calcareous shale, with thin argillaceous and crystalline limestone beds intercalated	11″	8′ 9″	30′ 8″
Blue-gray, bedded, somewhat argillaceous limestone	9″	7′10″	29′ 9″
Greenish, bedded, slightly calcareous shale, without prominent calcareous beds	1′ 4″	7′ 1″	29′ 0″
Beds of greenish, bedded, slightly calcareous shale with numerous intercalated 1-inch beds of purplish, coarse-textured, highly fossiliferous limestone, containing *Glyptorthis bellarugosa* and *Dinorthis sweeneyi* in abundance; limestones particularly abundant in base of the beds (faunule listed on p. 660)	4′11″	5′ 9″	27′ 8″
Green, laminated, bedded, slightly calcareous, shale	10″	10″	22′ 9″
Guttenberg member:			
Grayish, fine to medium-textured, somewhat argillaceous beds of limestone of shaly structure, grading down to beds of dark-gray to brownish, coarse-textured, fossiliferous limestone	7′ 2″	13′ 9″	21′11″

The type section of the Ion member is in the northwest quarter of Sec. 35, T. 96 N., R. 4 W. (Fairview Township, Allamakee County, Iowa). In this section (see Table V), the Ion member is largely of shale.

The lower beds of the Guttenberg are much like those at the

type section, and the Spechts Ferry member, 8 feet 2 inches in thickness, is composed of shale beds with intercalated limestones, similar to those at Spechts Ferry.

As one proceeds to Winneshiek County, he sees the "persistent body of shale" of which Calvin wrote. A good outcrop of the beds

FIG. 5.—The base of the Ion member lying on the top bed of the Guttenberg member at the type locality of the Ion member, Allamakee County, Iowa. The hammer lies on a limestone bed containing the *Glyptorthis bellarugosa* faunule. The limestone bed at the bottom of the figure is the top bed of the Guttenberg member.

is in the second ravine north of the road on the south line of the southwest quarter of Sec. 13, T. 98 N., R. 7 W. (Glenwood Township). This section is similar to the type section of the formation at Decorah, 8 miles to the west. As may be seen, the two upper members of the formation are much more argillaceous than in sections farther to the southeast; the Spechts Ferry member is of the same character as in those sections, though it seems to be much thicker. See Table VI.

The Spechts Ferry member is well exposed in a ravine paralleling

TABLE VI

SECTION IN SECTION 13, GLENWOOD TOWNSHIP, WINNESHIEK COUNTY, IOWA

	Thickness of Bed	From Top of Bed to—	
		Base of the Member	Base of Spechts Ferry
GALENA formation:			
Prosser limestone:			
Heavy beds of gray, fine-textured, sparsely fossiliferous limestone			
DECORAH formation:			
Ion member:			
Greenish, bedded, calcareous shale, containing well-preserved fossils in abundance, and nodules of argillaceous limestone—the Prasopora zonule	1′1″	19′ 5″	40′ 0″
Blue-gray, fine-textured, slightly argillaceous, non-fossiliferous limestone	1′0″	18′ 4″	38′11″
Blue-gray to purplish, medium- to coarse-textured limestone, the upper part highly fossiliferous and argillaceous	1′3″	17′ 4″	37′11″
Greenish, calcareous shale beds with intercalated nodular beds of buff to gray, fine-textured, argillaceous limestone	5′9″	16′ 1″	36′ 8″
Bed of gray, medium-textured, laminated, non-fossiliferous, argillaceous limestone	7″	10′ 4″	30′11″
Greenish-gray, calcareous shale	5½″	9′ 9″	30′ 4″
Grayish, medium-textured, non-fossiliferous, argillaceous limestone	9½″	9′ 3½″	29′10½″
Greenish, calcareous shale	4″	8′ 6″	29′ 1″
Beds of gray, argillaceous limestone	7″	8′ 2″	28′ 9″
Greenish, calcareous shale containing nodular beds of grayish, argillaceous limestone	3′1″	7′ 7″	28′ 2″
Purplish, coarse-textured, crystalline, highly fossiliferous limestone containing *Glyptorthis bellarugosa*	2″	4′ 6″	25′ 1″
Greenish, calcareous shale with limestone nodules	8½″	4′ 4″	24′11″
Purplish, coarse-textured, crystalline limestone	1½″	3′ 7½″	24′ 2½″
Greenish, non-fossiliferous, bedded, calcareous shale containing beds of nodular limestone; very argillaceous at base	3′6″	3′ 6″	24′ 1″
Guttenberg member:			
Beds of bluish-gray, fine-textured, argillaceous, sparsely fossiliferous limestone in a single ledge, the upper surface of which is pitted	1′1″	10′ 0″	20′ 7″
Two-inch, somewhat nodular beds of limestone, most of which is gray, fine-textured, hard and massive in character, some, coarse-textured and crystalline; fossils on the surfaces of beds; limestone intercalated with beds of plastic, non-calcareous, laminated shale, in the			

TABLE VI—*Continued*

	Thickness of Bed	From Top of Bed to—	
		Base of the Member	Base of Spechts Ferry
lower part dark blue in color, in the upper part, greenish	3′7″	8′11″	19′ 6′
Beds of grayish, medium-textured, somewhat argillaceous limestone	8″	5′ 4″	15′11″
One- to 2-inch beds of argillaceous limestone intercalated with somewhat calcareous blue-green shale	1′3″	4′ 8″	15′ 3″
Three beds of bluish, fine-textured limestone with intercalated blue laminated shale	6″	3′ 5″	14′ 0″
Dark blue laminated, plastic, non-calcareous shale, with bed of fine-textured limestone near top	1′8″	2′11″	13′ 6″
Bluish, hard, fine-textured, non-fossiliferous limestone bed	2″	1′ 3″	11′10″
Blue, plastic, laminated shale	2″	1′ 1″	11′ 8″
Bluish, hard, fine-textured, non-fossiliferous limestone bed	2″	11″	11′ 6″
Blue, laminated, plastic, non-calcareous shale	9″	9″	11′ 4″

and west of the road running northeastward just west of Connors (West Ridge Church), Union Prairie Township, Allamakee County. The section is in the southwest quarter of the southeast quarter of Sec. 12, T. 98 N., R. 7 W. (Glenwood Township, Winneshiek County, Iowa).

SUMMARY AND INTERPRETATION OF LITHOLOGY

In summarizing the lithology of the Decorah formation, each of the members will be discussed as a unit.

Spechts Ferry member.—The Spechts Ferry member has a rather uniform thickness throughout its outcrop. Not only is the thickness constant, but the several beds maintain similar lithologies and faunules at about the same horizons over considerable areas. The member does not exhibit the striking facies changes that appear in the higher members, but there is a marked replacement of shale by limestone in the southeasternmost outcrops.

There is a sharp lithologic break at the base of the Spechts Ferry, so that it is differentiated readily from the underlying Platteville. In some outcrops there is a basal shale-conglomerate. The lithologic

break does not evidence a hiatus at this horizon; it should be interpreted rather as indicating an uplift in the land mass from which the clastic sediments were being eroded. The evidence precludes

FIG. 6.—Intercalated limestone and shale beds of the Guttenberg member about 2 feet from the top in Sec. 13, Glenwood Township, Winneshiek County, Iowa. The coin is a half-dollar.

there being an unconformity at the top of the Platteville, and there seems to be no evidence of an erosional disconformity of any magnitude. The top of the Platteville is everywhere a bed of gray, fine-textured, hard limestone; its upper surface usually is undulating, but in no section is there evidence that the top of the formation has been removed by erosion. It is difficult to believe that the Platte-

ville has been eroded from an area as great as that of the Spechts Ferry outcrop without the resulting irregular surface giving a perceptible variation to the thickness of the member.

The differences in rock facies may explain also such faunal changes as accompany them. There may have been some channel-

FIG. 7.—Upper part of the Spechts Ferry member in the section west of Connors, in Sec. 12, Glenwood Township, Winneshiek County, Iowa. The ledges jutting out in the middle of the figure are 8 feet above the base of the member; the hammer lies on a bed at 5 feet.

ing during the deposition of the member. This would seem an explanation of the lensing of some of the limestone beds. In other cases, the calcification of the beds may have proceeded irregularly; in such instances, a limestone bed can be traced into a shale band that contains the same fossils in a poorer state of preservation.

Guttenberg member.—The Guttenberg member, typically a limestone, grades northward into shales. The beds become more argillaceous in two ways. First, beds of non-calcareous shale become intercalated with the limestone beds, and in Winneshiek County

occur throughout the member; and second, the limestone becomes increasingly argillaceous. The change in lithology is paralleled by an increase in the number of specimens of Bryozoa and Mollusca. In the southeastern outcrops there is an abrupt lithologic change from the Spechts Ferry shales to the Guttenberg limestones; to the northwest, where both are shales, it is difficult to draw the line between the two members on the basis of the lithology.

There is no evidence in the lithology of there having been erosion prior to the deposition of the Guttenberg. In outcrops from Platteville, Wisconsin, to Waukon, Iowa, the top of the Spechts Ferry is commonly a heavy bed of bluish, hard limestone containing minute pyritic granules and fossils.

Ion member.—The Ion member of the Decorah formation presents three dominant facies: dolomite, limestone, and shale, the first representing a secondary alteration of the second. The limestones in many of the Dubuque County sections have been metasomatically replaced by dolomite. These southern limestones grade northward into calcareous shales, the limestones becoming continuously more and more argillaceous. Even in the most argillaceous facies, the calcareous nodules are abundant; and there are at least two shaly zones, those of the *Glyptorthis bellarugosa* zonule near the base of the member, and of the *Prasopora simulatrix* zonule near the top of the member, that retain their argillaceous character throughout the outcrop, even though the limestones adjacent to them may be dolomitized.

The continuity of lithology and thickness precludes there being a notable erosional disconformity at the base of the member; in the northern part of the outcrop, there is a marked lithologic disconformity, for the base of the Ion is much more argillaceous than the top of the Guttenberg. The top of the Ion grades into the base of the Galena lithologically. The base of the Galena becomes argillaceous in northern Iowa and Minnesota, and the upper Ion limestones in Iowa are much like those of the Galena.

If there be a hiatus immediately above the Decorah, there seems to have been no erosion during post-Decorah time, for the top zonule of the Decorah, though thin, persists over a large area. This absence of an erosional disconformity of course does not prove that there

was not a cessation of deposition immediately following the deposition of the youngest Decorah sediments.

FAUNA

Spechts Ferry member.—The Spechts Ferry member is consistently fossiliferous throughout its outcrop. One of the facies, the "glass-rock" limestone referred to the base of the member, contains the following faunule about a foot above its base in a ravine in the center

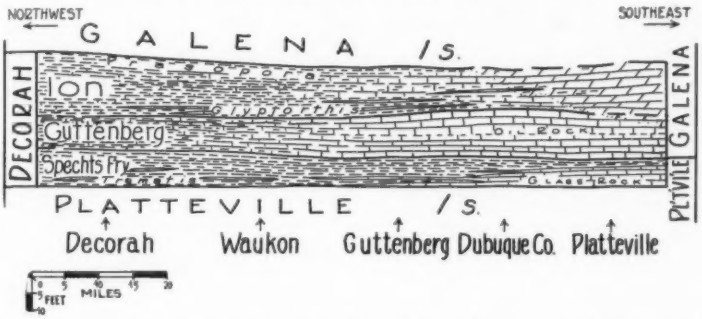

FIG. 8.—Longitudinal section of the Decorah formation from northern Iowa to northwestern Illinois.

of Sec. 20, T. 3 N., R. 1 W. (Platteville Township, Grant County, Wisconsin). This section has been described on page 644.

"GLASS-ROCK" FAUNULE, WEST OF PLATTEVILLE, WISCONSIN

Pionodema subaequata (Conrad)	u*	*Aparchites* sp.	c
Rafinesquina sp.; cf. *R. alternata* (Conrad)	a	*Bythocypris(?) granti* Ulrich	a
Raphistoma(?) sp.	c	*Eurychilina ventrosa* Ulrich	u
Bathyurus sp.; cf. *B. spiniger* (Hall)	u	*Eurychilina* sp.	u
Isotelus sp.; aff. *I. walcotti* Ulrich	c	*Krausella arcuata* Ulrich	c
Aparchites trentonensis Ulrich	c	*Macronotella scofieldi* Ulrich	c
Aparchites neglectus Ulrich	c	*Primitia* sp.	p

* The following abbreviations are used in referring to the abundance of the fossils: "aa," very abundant; "a," abundant; "c," common; "f," frequent; "u," uncommon; "r," rare; "p," present, probably not common.

This fauna has not been recognized in Iowa, and it is possibly older than the base of the typical Spechts Ferry member.

Farther to the northwest, *Pionodema subaequata* (Conrad) and *Rafinesquina alternata* (Conrad) are abundant in many of the green shale beds throughout the member. There is a persistent faunule,

which may be called the *Trematis punctostriata* faunule, that occurs in gray, fine-textured, soft, vertically-jointed limestone beds from 1 to 4 feet from the bottom of the member. It has been recognized in Winneshiek County, and as far to the southeast as Patch Grove Township, Grant County, Wisconsin. The zonule is well exposed in a ravine east of the valley in the northeast quarter of Sec. 29, T. 98 N., R. 7 W. (Glenwood Township, Winneshiek County, Iowa), where it occurs as a limestone bed $3\frac{1}{2}$ feet above the Platteville. It contains the following faunule:

LOWER SPECHTS FERRY *Trematis punctostriata* FAUNULE, EAST OF DECORAH, IOWA

Alga(?)	p	*Holopea* sp.	p
Lingula clathrata Winchell and Schuchert	a	*Hormotoma subangulata* Ulrich and Scofield	p
Lingula (*Glossina*) sp.	c	*Liospira* sp.	p
Trematis punctostriata Hall	a	*Lophospira peracuta* Ulrich and Scofield	f
Pionodema subaequata (Conrad)	c	*Lophospira* sp.	p
Rafinesquina sp.; cf. *R. alternata* (Conrad)	a	*Orthoceras* sp.; cf. *O. multicameratum* Hall	f
Strophomena sp.; cf. *S. filitexta* Hall	c	*Spyroceras bilineatum* (Hall)	c
Zygospira recurvirostris (Hall)	f	*Isotelus* sp.; cf. *I. walcotti* Ulrich	c
Cyrtodonta janesvillensis Ulrich and Scofield	f	*Pterygometopus eboraceus* Clarke	c
Endodesma sp.	p	*Leperditia macra* Ulrich	p

Fossils are abundant in beds of dark-blue, hard, pyritic shale near the top of the member. Shales of this character occur in the upper 1 foot of the member in a section along the stream just west of United States Highway 18 in the extreme northeast quarter of Sec. 32, T. 6 N., R. 5 W. (Patch Grove Township, Grant County, Wisconsin) at a locality known locally as "Big Spring," Wisconsin; the beds contain the following fossils:

UPPER SPECHTS FERRY FAUNULE, NEAR PATCH GROVE, WISCONSIN

Crinoid stems	*Stictoporella frondifera* Ulrich
Arthroclema striatum Ulrich	*Crania setigera* Hall
Arthropora simplex Ulrich	*Crania* sp.
Arthropora bifurcata Ulrich	*Cyclospira* (*?*) sp.
Ceramoporella sp.; cf. *C. inclusa* Ulrich	*Pionodema subaequata* (Conrad)
Cyphotrypa informis (Ulrich)	*Rhynchotrema* sp.
Helopora divaricata Ulrich	*Strophomena* sp.; cf. *S. filitexta* Hall (part)
Rhinidictya major Ulrich	*Zygospira* sp.; cf. *Z. recurvirostris* (Hall)
Rhinidictya mutabilis Ulrich	*Ceraurus pleurexanthemus* Green

Isotelus sp.; cf. *I. walcotti* Ulrich
Pterygometopus sp.
Eurychilina subradiata Ulrich
Schmidtella sp.
Tetradella sp.; aff. *T. simplex* (Ulrich)

Guttenberg member.—There is very little variation in the species present in the typical limestone of the Guttenberg from its base to its top. A characteristic fauna has been collected from the limestone along Galena River back of the old mill 1 mile south of Milbrig, in the southwest quarter of the southeast quarter of Sec. 34, T. 29 N., R. 1 E. (Council Hill Township, Jo Daviess County, Illinois):

GUTTENBERG FAUNULE, NEAR GALENA, ILLINOIS

Streptelasma sp.	u	*Liospira angustata* Ulrich and Scofield	c
Crinoid stems	c	*Liospira modesta* Ulrich and Scofield	c
Batostoma winchelli Ulrich	f	*Liospira* sp.	p
Cyphotrypa sp.	u	*Lophospira oweni* Ulrich and Scofield	c
Rhinidictya sp.; cf. *R. mutabilis* Ulrich	f	*Raphistoma peracutum* Ulrich and Scofield	f
Camarella sp.; aff. *C. panderi* Billings	r	*Scenella* sp.	r
Dalmanella rogata (Sardeson)	c	*Conularia granulata* Hall	r
Lingulasma galenense Winchell and Schuchert	p	*Conularia trentonensis* Hall	f
Orthis tricenaria Conrad	f	*Hyolithes baconi* Whitfield	c
Pionodema subaequata (Conrad)	c	*Hyolithes* sp.	p
Plectambonites (Sowerbyella) sp.	a	*Orthoceras junceum* Hall	u
Pseudolingula sp.	f	*Orthoceras multicameratum* Hall	c
Rafinesquina alternata (Conrad)	a	*Spyroceras bilineatum* (Hall)	c
Rhynchotrema sp.	u	*Bathyurus spiniger* (Hall)	c
Schizocrania filosa (Hall)	f	*Bumastus milleri* Billings	a
Strophomena filitexta Hall	a	*Ceraurus dentatus* Raymond and Barton	a
Trematis ottawaensis Billings	r	*Goldius lunatus* (Billings)	f
Ctenodonta compressa Ulrich	a	*Isotelus* sp.; cf. *I. gigas* (Dekay)	f
Cyrtodonta glabella Ulrich	f	*Isotelus* sp.; cf. *I. walcotti* Ulrich	c
Cyrtodonta huronensis Billings	f	*Pterygometopus eboraceus* Clarke	a
Cyrtodonta sp.; cf. *C. rotulata* Ulrich and Scofield	p	*Thaleops ovata* Conrad	c
Modiolopsis sp.	p	*Bythocypris(?) granti* (Ulrich)	r
Phragmolites sp.; cf. *Conradella obliqua* Ulrich and Scofield	f	*Cytherella (?) rugosa* (Jones)	r
Gyronema duplicatum Ulrich	f	*Eurychilina reticulata* Ulrich	r
Hormotoma sp.; cf. *H. salteri* Ulrich	c	*Schmidtella incompta* Ulrich	r

As one goes from the limestones of the southern part of the outcrop to the argillaceous limestones in southern Allamakee County, there are certain faunal changes, though many of the species are common to both regions. There is a fine exposure of the argillaceous limestone facies along the east bank of the stream in the extreme

northeast quarter of Sec. 24, T. 97 N., R. 6 W. (Ludlow Township, Allamakee County, Iowa), from which the following species have been collected:

GUTTENBERG FAUNULE, SOUTH OF WAUKON, IOWA

Streptelasma corniculum Hall	a	*Clathrospira conica* Hall	c
Lichenocrinus crateriformis Hall	f	*Eotomaria supracingulata* (Billings)	p
Favositella laxata (Ulrich)	a	*Hormotoma* sp.; cf. *H. gracilis* Hall	c
Amplexopora sp	c	*Lophospira* sp	f
Eridotrypa exigua Ulrich	c	cf. *Opheletina* sp	r
Nematopora ovalis Ulrich	c	*Scenella* sp	r
Rhinidictya paupera Ulrich	c	*Sinuites cancellatus* (Hall)	a
Camarella sp.; aff. *C. panderi* Billings	r	*Hyolithes baconi* Whitfield	f
Crania sp	u	*Cyrtoceras houghtoni* Clarke	f
Orthis tricenaria Conrad	c	*Endoceras proteiforme* (Hall)	u
Pionodema subaequata (Conrad)	c	*Orthoceras amplicameratum* Hall	a
Rafinesquina alternata (Conrad)	c	*Orthoceras* sp	p
Rhynchotrema sp.; cf. *R. minnesotense* (Sardeson)	c	*Spyroceras bilineatum* (Hall)	c
Schizocrania filosa (Hall)	u	*Bumastus milleri* Billings	f
Strophomena filitexta Hall	c	*Ceraurus dentatus* Raymond and Barton	u
Strophomena sp.; cf. *S. trentonensis* Winchell and Schuchert	f	*Isotelus gigas* (Dekay)	f
Ctenodonta compressa Ulrich	c	*Isotelus* sp.; cf. *I. walcotti* Ulrich	f
Cyrtodonta glabella Ulrich	f	*Pterygometopus eboraceus* Clarke	u
Modiolopsis sp	p	*Cytherella(?) rugosa* (Jones)	p

Ion member.—In the northern part of the outcrop, two zonules in the Ion member are particularly fossiliferous. The lower of these, which may be designated the "*Glyptorthis bellarugosa* zonule," has a faunule that occurs in the purplish, coarse-textured limestones intercalated with the greenish, somewhat calcareous shales in the lower third of the member. At the type section of the member, in the northwest quarter of Sec. 35, T. 96 N., R. 4 W. (Fairview Township, Allamakee County, Iowa), the limestone beds 2 feet above the base of the member, and the shale immediately adjacent to them, contain the following species (the section has been described on page 650):

LOWER ION, *Glyptorthis bellarugosa* FAUNULE, NEAR ION, IOWA

Raufella sp	c	*Cyphotrypa informis* (Ulrich)	p
Streptelasma corniculum Hall	c	*Pachydictya fimbriata* Ulrich	c
Arthroclema cornutum Ulrich	c	*Pachydictya occidentalis* Ulrich	f
Arthropora bifurcata Ulrich	c	*Rhinidictya exigua* Ulrich	p

Rhinidictya mutabilis Ulrich..... a
Dalmanella rogata (Sardeson) f
Dinorthis sweeneyi (Winchell and Schuchert)..... a
Hebertella (Glyptorthis) bellarugosa (Conrad)..... a
Orthis tricenaria Conrad..... c
Pholidops minor Winchell and Schuchert..... c
Plectambonites (Sowerbyella) sp..... a
Rafinesquina inquassa (Sardeson).... u
Rhynchotrema sp..... f
Strophomena filitexta (Hall)..... c
Isotelus sp..... p
Bollia unguloidea Ulrich..... a
Bythocypris sp..... p
Ceratopsis sp.; aff. *C. chambersi* Ulrich u
Cytherella(?) arcta Ulrich..... f
Cytherella(?) rugosa (Jones)..... c
Cytherella(?) sp..... c
Eridoconcha oboloides Ulrich and Bassler..... f
Eurychilina ventrosa Ulrich..... u
Halliella labiosa Ulrich..... u
Jonesella obscura Ulrich..... f
Primitiella sp.; cf. *P. constricta* Ulrich f
Schmidtella affinis Ulrich..... f
Schmidtella sp..... f
Scofieldia bilateralis (Ulrich)..... r
Steusloffia(?) sp.; aff. *S. signata* (Krause)..... c
Steusloffia(?) sp..... u
Tetradella sp..... f
cf. *Drepanella* sp..... f
cf. *Tetradella* sp..... c
Lepidocoleus jamesi (Hall and Whitfield)..... c

The zonule at the top of the member, the Prasopora zonule, characterized by a variety of *Prasopora simulatrix* Ulrich, is replete with species of Bryozoa, Ostracoda, and Brachiopoda. The following species were collected in the outcrop along Primary Highway 9, just east of Church, in Sec. 32, T. 99 N., R. 4 W. (Lansing Township, Allamakee County, Iowa):

UPPER ION, PRASOPORA FAUNULE, CHURCH, IOWA

Raufella sp..... c
Crinoid stems..... a
Arthroclema striatum Ulrich..... a
Arthropora bifurcata Ulrich..... c
Batostoma humile Ulrich..... a
Cyphotrypa acervulosa (Ulrich)..... f
Cyphotrypa sp..... p
Hallopora ampla (Ulrich)..... c
Homotrypa subramosa Ulrich..... f
Mesotrypa quebecensis Ami..... c
Monticulipora arborea Ulrich..... r
Nematopora ovalis Ulrich..... c
Prasopora contigua Ulrich..... f
Prasopora fillmorensis Ulrich..... u
Prasopora simulatrix Ulrich var..... aa
Rhinidictya mutabilis Ulrich..... c
Ctenodonta sp..... r
Unidentified Gastropoda
Hyolithes sp..... r
Dalmanella rogata (Sardeson)..... a
Dinorthis meedsi (Winchell and Schuchert)..... c
Parastrophina rotundiformis (Willard) f
Plectambonites (Sowerbyella) sp..... c
Platystrophia extensa McEwan..... f
Platystrophia trentonensis McEwan... c
Pseudolingula galenensis (Winchell and Schuchert)..... f
Pseudolingula iowensis (Owen)..... c
Rhynchotrema decorahense Fenton and Fenton..... c
Rhynchotrema minnesotensis (Sardeson)..... f
Rhynchotrema wisconsinense Fenton and Fenton..... f
Strophomena septata Winchell and Schuchert..... u
Strophomena billingsi Winchell and Schuchert..... f

Strophomena sp.; cf. *S. filitexta* Hall.. f
Zygospira recurvirostris (Hall)..... c
Calymene senaria Hall..... c
Ceraurus dentatus Raymond and Barton..... r
Pterygometopus schmidti Clarke..... r
Aparchites trentonensis Ulrich..... f
Bollia unguloidea Ulrich..... aa
Bythocypris granti Ulrich..... f
Cytherella(?) sp..... a
Primitia sp.; cf. *P. mammata* Ulrich.. c
Primitia sp..... c
Primitiella sp..... c
Schmidtella incompta Ulrich..... a
Lepidocoleus jamesi (Hall and Whitfield)..... c

FIG. 9.—An outcrop of the Prasopora zonule at the top of the Ion member of the Decorah formation in a small ravine north of the road in the extreme S.E. $\frac{1}{4}$ of Sec. 15, T. 98 N., R. 7 W. (Glenwood Township, Winneshiek County, Iowa). The shale beds at the top of the figure are the top beds of the member.

That the upper beds of the Ion member contain a prolific microfauna is evidenced by their faunule in an outcrop in a small ravine crossing the road in the northeast quarter of the southwest quarter

of Sec. 6, T. 98 N., R. 7 W. (Glenwood Township, Winneshiek County, Iowa). The upper 7 feet of the member contain the following species of microfossils:

UPPER ION MICROFAUNULE, NEAR DECORAH, IOWA

Raufella sp.	a	*Eurychilina ventrosa* Ulrich	c
Arthroclema armatum Ulrich	c	*Eurychilina(?)* sp.; cf. *E.(?) subaequata* Ulrich	f
Escharopora sp.	f	*Halliella labiosa* Ulrich	f
Helopora sp.	f	*Krausella* sp.; cf. *K. arcuata* Ulrich	r
Mitoclema(?) sp.	f	*Moorea punctata* Ulrich	u
Nematopora granosa Ulrich	f	*Primitia* sp.; cf. *P. (Laccoprimitia) celata* (Ulrich)	f
Nematopora ovalis Ulrich	c	*Primitia* sp.; cf. *P. centralis* Ulrich	u
Pachydictya sp.	f	*Primitia* sp.; cf. *P. mammata* Ulrich	a
Prasopora sp.	c	*Primitiella* sp.; aff. *P. constricta* Ulrich	c
Rhinidictya sp.	c	*Schmidtella affinis* Ulrich	f
Unidentified Brachiopoda, Pelecypoda, Gastropoda, conodonts, Trilobita		*Schmidtella incompta* Ulrich	c
Aparchites concinnus (Jones)	r	*Schmidtella umbonata* Ulrich	f
Aparchites sp.	c	*Schmidtella* sp.; cf. *S. subrotunda* Ulrich	u
Beyrichia sp.; aff. *B. strictispiralis* Jones	r	*Scofieldia bilateralis* (Ulrich)	u
Bollia unguloidea Ulrich	a	*Tetradella* sp.; cf. *T. lunatifera* Ulrich not *Strepula lunatifera* Ulrich	f
Bythocypris sp.; cf. *B. curta* Ulrich	p	*Tetradella* sp.	f
Bythocypris cylindrica (Hall)	f	cf. *Beyrichia* sp.	u
Ctenobolbina sp.	u	cf. *Ctenobolbina* sp.	u
Cytherella(?) arcta Ulrich	c	cf. *Krausella* sp.	r
Cytherella(?) rugosa (Jones)	c	cf. *Tetradella* sp.	r
Cytherella(?) sp.	f	*Lepidocoleus jamesi* (Hall and Whitfield)	c
Dicranella marginata Ulrich	r		
Eridoconcha oboloides Ulrich and Bassler	c		
Eurychilina symmetrica (Ulrich)	f		

CORRELATION OF THE DECORAH

Correlation with the standard section.—The following formations comprise the Mohawkian of the typical section in New York and Ontario, a section with which the Decorah formation should be correlated; see Table VII.

The Lowville, Leray, and Watertown have been classified as Black River by all recent writers; the Hull and younger formations have been included in the Trenton group. Raymond[1] and Johnston[2]

[1] P. E. Raymond, "Trenton Group in Ontario and Quebec," *Geol. Survey, Canada, Summary Rept. for 1912* (1913), p. 346; and "Fauna of the Trenton Group," *Geol. Survey, Canada, Museum Bull. 31* (1921), p. 1.

[2] W. A. Johnston, *Geol. Survey, Canada, Summary Rept. for 1912* (1913), pp. 196. etc.

have classified the Rockland as Trenton. Ulrich[1] has correlated the Hull formation, immediately above the Rockland, with the Curdsville formation of Kentucky, which he classifies as the base of the Trenton.

TABLE VII

TRENTON group		Gloucester
		Collingwood
		Upper Cobourg
		Lower Cobourg
		Sherman Fall*
		Hull
		Rockland
BLACK RIVER group	Chaumont†	Watertown
		Glenburnie‡
		Leray
	Lowville	

* The Sherman Fall formation, for which the name has been suggested by J. J. Galloway, is defined here as the "Prasopora beds" or "Trenton (restricted)" of Raymond, Johnston, and others. The formation takes its name from Sherman Fall, in the Trenton Falls gorge of West Canada Creek, Oneida County, New York. Its base, a bed in which *Prasopora simulatrix orientalis* is abundant, lies immediately above a stratum of massive, dark-blue limestone about 3 feet thick that is conspicuous in the side of the gorge along the path above Sherman Fall, the bed A_4 of Prosser and Cummings (*15th Ann. Rept. State Geologist New York for 1895* [1897], p. 615). The formation includes about 105 feet of thin-bedded limestones with shaly partings, extending to the seam in the cliff of upper High Fall about 20 feet from the top of the fall; it comprises zones F to K of Raymond (*Bull. Amer. Paleon.*, No. 17 [1903]), zone A_5, and most of zone A_6 of Prosser and Cummings.

† The Chaumont formation, here proposed, takes its name from Chaumont Bay, Lake Ontario, in the vicinity of which the members of the formation are well exposed. It includes beds younger than the Lowville and older than the Rockland in this region. There is no presumption that the members have had continuous or similar histories.

‡ The Glenburnie member of the Chaumont formation, here proposed, includes two feet of argillaceous limestone lying above the Leray and below the Watertown at the type section in a small quarry west of the road in Lot 22, Conc. V, a mile southwest of the hamlet of Glenburnie, Kingston Township, Frontenac County, Ontario. The type section is described in this paper.

Ulrich[2] has classified the Decorah as younger than the Watertown and older than the Rockland. Raymond[3] has correlated the Decorah with the Rockland and Hull formations of the Trenton group.

[1] E. O. Ulrich in R. S. Bassler, "Bibliographic Index of American Ordovician and Silurian Fossils," *U.S. Nat. Museum, Bull. 92* (1915), Pl. 2.

[2] *Ibid.*

[3] P. E. Raymond, "Correlation of the Ordovician Strata of the Baltic Basin," *Bull. Museum Comp. Zoöl., Harvard*, Vol. LVI (1916), Pl. 8.

A Decorah fauna has been recognized as occurring in the Kingston region;[1] the stratigraphic relations of the beds containing the fauna have not been described. The type section of the Glenburnie member of the Chaumont formation, within which the fauna occurs, in a small quarry west of the road in Lot 22, Conc. V, Kingston Township, Frontenac County, Ontario, a mile southwest of the

TABLE VIII

TYPE SECTION OF GLENBURNIE MEMBER, NORTH OF KINGSTON, ONTARIO

	Thickness of Bed
BLACK RIVER group:	
CHAUMONT formation:	
Watertown limestone:	
Rather heavy beds of dark-colored, fine to medium-textured limestone containing *Stromatocerium rugosum, Streptelasma profundum Tetradium fibratum, Strophomena* sp., *Actinoceras tenuifilum, Orthoceras reticameratum,* and *O. multicameratum*	2′0″
In a lens at the base near the south end of the quarry; gray, coarse-textured, somewhat brecciated limestone.....as much as	6″
Glenburnie member:	
Yellow-weathering, very argillaceous shaly limestone intercalated with thin beds of shale; highly fossiliferous; fauna listed below	2′0″
Leray limestone:	
Dark-gray limestone of varying character; some beds filled with *Tetradium fibratum;* a bed near the base with conspicuous ripple marks exposed	8′6″

hamlet of Glenburnie, reveals the relations of these beds; see Table VIII.

The Glenburnie member contains a prolific fauna in which bryozoans are particularly abundant:

GLENBURNIE FAUNULE, TYPE SECTION NEAR KINGSTON, ONTARIO

Columnaria (?) sp.	f	*Rhinidictya mutabilis* Ulrich	aa
Streptelasma profundum Hall	c	*Rhinidictya trentonensis* Ulrich	c
Tetradium fibratum Safford	u	*Camarella* sp.; cf. *C. panderi* Billings	c
Crinoid stems and plates	a	*Rhynchotrema* sp.	c
Arthroclema sp.	r	*Strophomena* sp.; aff. *S. billingsi* Winchell and Schuchert	f
Escharopora suberecta Ulrich	f		
Hemiphragma irrasum Ulrich	c	*Cyrtodonta* sp.; cf. *C. huronensis* (Billings)	f
Pachydictya fimbriata Ulrich	c		
Pachydictya occidentalis Ulrich	f	*Orthoceras recticameratum* (Hall)	f

[1] E. O. Ulrich in "Geology of Kingston and Vicinity," *Ontario Bureau Mines*, Vol. XXV, Part III (1916), p. 43.

Spyroceras bilineatum (Hall)	u	*Primitia* sp	r
Bathyurus spiniger Hall	c	*Schmidtella* sp.; cf. *S. incompta* Ulrich	c
Bumastus milleri Billings	f	*Schmidtella* sp	r
Aparchites trentonensis Ulrich	u	*Tetradella quadrilirata* Ulrich	f
Aparchites sp	f	*Tetradella* sp	u
Aparchites sp	c	*Tetradella* (*Kiesowia*) sp	r
Eridoconcha oboloides Ulrich and Bassler	f	*Tetradella* (*Steusloffia*) sp	r
Primitia sp; aff. *P. celata* Ulrich	c		

The composition of the Glenburnie fauna, with its characteristic lower Decorah molluscoids, is significant; it is to be correlated with the Spechts Ferry and part of the Guttenberg member of the Decorah formation.

The Glenburnie member does not occur at Watertown, New York, nor is it found southeast of Watertown at Lowville and Dry Sugar River. The presence of a disconformity between the Leray and Watertown in this region has been anticipated by Ulrich.[1] It seems that the Glenburnie fauna is represented in the "upper Leray" of the Ottawa region.[2]

The Watertown has been believed to be of very local distribution; a disconformity has been presumed to be widespread at this horizon. The Glenburnie section reveals the presence of the Watertown in the Kingston region, and beds of similar stratigraphic relations have been observed as far to the west as Napanee, Ontario. With the present limited knowledge of the Watertown fauna, it is difficult to separate the Leray and Watertown on a faunal basis. Ruedemann[3] noted that the characteristic Watertown cephalopods appear in the Leray but that the Watertown at the type locality lacks certain guide fossils of the Leray. It might be presumed that the upper beds of the "Leray" or Coboconk limestone[4] in the Lake Simcoe region are of Watertown age, and are not identified, first, because the fauna cannot be distinguished from a Leray fauna, and second, because the intermediate Glenburnie fauna is absent. As a

[1] E. O. Ulrich in "Geology of the Thousand Islands Region," *New York State Museum Bull. 145* (1910), p. 85.

[2] Faunal lists in A. E. Wilson, "Range of Certain Lower Ordovician Faunas in the Ottawa Valley," *Geol. Survey, Canada, Bull. 33* (1921), p. 19.

[3] Rudolf Ruedemann, "Geology of the Thousand Islands Region," *New York State Museum Bull. 145* (1910), p. 84.

[4] W. A. Johnston, "Simcoe District, Ontario," *Geol. Survey, Canada, Summary Rept. for 1910* (1911), p. 189.

rule, a disconformity can be proved by the presence in adjacent beds of faunas that in other regions are separated by an intermediate fauna, but the absence of a fauna between two beds that in themselves are separated by non-significant beds does not prove the pres-

FIG. 10.—Leray, Glenburnie, and Watertown members of the Chaumont formation exposed in quarry west of road, Lot 22, Conc. V, Kingston Township, Frontenac County, Ontario. The Glenburnie beds lie between the marks in the upper part of the figure.

ence of a disconformity. No section is known in the Lake Simcoe region in which the relations of the beds are so shown as to prove or to disprove the presence of either the Glenburnie or the Watertown in that region. Limited faunules from the Lake Simcoe region suggest that the Glenburnie may be present at least locally, but the evidence is not conclusive.

There is a lack of significant sections at the Black River—Tren-

ton contact in the region northwest of Watertown; this has precluded the learning of the precise stratigraphic relations of the beds. There is nothing to evidence their being different from what they are south of Watertown, where at Lowville, Martinsburg,[1] and Leyden, New York, the Rockland lies directly on the Watertown.

There are few fossils common to both the Watertown and the Decorah. On the basis of order of position, the Watertown equivalent, if present, should be above the lower Guttenberg, correlated with the Glenburnie, and below the Ion, which is of Rockland age. The presence of *Gonioceras* sp. in the upper Guttenberg in Allamakee County, Iowa, seems to support the correlation of this horizon with the Watertown.

Inasmuch as the upper Decorah Ion member is no younger than the Rockland formation, the character of its fauna is significant in the classification of the Rockland. The Ion member, particularly in its upper part, contains a fauna with Trenton affinities. It has an abundance of specimens of such characteristic Trenton and later genera as *Calymene*, *Parastrophina*, *Plectambonites* (*Sowerbyella*) and *Platystrophia*, and species such as *Ceraurus dentatus* and *Prasopora simulatrix*. It may be granted that the presence of specimens of a genus or species in beds of one age in the type section does not preclude their being found in older beds in other regions, but the preponderance of Trenton forms in the Ion member leads one to the conclusion that the upper Decorah is Trenton, and hence that correlative Rockland formation should be classified as Trenton.

The Spechts Ferry and Guttenberg members, the lower part of the Decorah formation, are thus to be correlated with the Glenburnie

	Ion member	Rockland formation		Trenton group
Decorah formation	Guttenberg member Spechts Ferry member	Watertown member Glenburnie member	Chaumont formation	Black River group

and Watertown members of the Chaumont formation of the Black River group in the type section of the Mohawkian; the Ion member is of the same age as the Rockland formation at the base of the Trenton group.

[1] T. H. Clark, "Section in the Trenton Limestone at Martinsburg, New York," *Bull. Museum Comp. Zoöl., Harvard*, Vol. LXIII (1919), p. 9.

Correlation with Missouri.—In southeastern Missouri the following Mohawkian formations crop out: Kimmswick limestone, "Decorah" formation, and Plattin limestone.

The "Decorah" formation is sometimes considered as the "Decorah" member of the Plattin formation. The fauna of the formation indicates that it is equivalent at least in part to the Spechts Ferry member of the Decorah formation in Iowa. The fauna of the Ion member seems to be lacking in the Missouri "Decorah." The Kimmswick formation lies disconformably on the "Decorah"; in some places the whole of the "Decorah" seems to have been eroded prior to Kimmswick time, for the Kimmswick is reported as lying

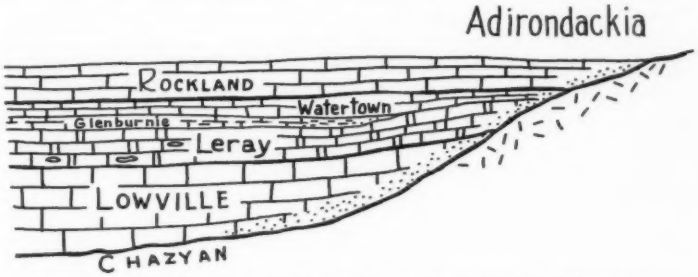

FIG. 11.—Restored section west from Adirondackia at the close of Rockland time, showing the overlaps of the younger formations, and the offlapping Glenburnie member.

disconformably on the Plattin formation in some sections.[1] The fauna of the basal Kimmswick has lower Trenton affinities, and it may be of Rockland age. If this be the case, the base of the Kimmswick formation should be correlated with the Ion member of the Decorah formation; this correlation has not been established.

The Missouri "Decorah" formation thus correlates with at least the Spechts Ferry member of the Decorah formation; and the base of the Kimmswick formation may be of Ion age.

Correlations with other regions.—Faunas of Decorah age have been listed from several other rather widely distributed regions. Dowling[2] listed a limited faunule from the Winnepeg sandstone of Manitoba; the faunule suggests that at least a part of the formation

[1] R. F. Flint, "Geology of the Altenberg Quadrangle, Missouri," *Missouri Bureau Geol. Mines* (in manuscript).

[2] D. B. Dowling, "Geology of the West Shore and Islands of Lake Winnepeg," *Geol. Survey, Canada, Ann. Rept.*, Vol. XI (1901), Part F, p. 60.

is of Decorah age. The Decorah fauna has been recognized in sections in deep wells in Kansas and Nebraska;[1] the faunules include lower Decorah fossils.

In Kentucky, the Decorah fauna is reported as lying on the Carters limestone of Chaumont age, and *below* the Curdsville, containing the Hull fauna;[2] the Rockland formation of the standard section would thus be represented by a hiatus. Raymond[3] has correlated the Curdsville with the Rockland. In Maryland and Pennsylvania, the Echinosphaerites bed contains the Glenburnie fauna.[4] The overlying beds are reported as being younger than the Rockland; they seem to have Rockland affinities.

There is thus evidence that during the time that the Decorah sediments were being deposited in Iowa and Minnesota, beds of the same age were being laid down over an extensive area in east-central North America; the Glenburnie fauna seems a little less widespread than that of the base of the Trenton.

GEOLOGIC HISTORY

In Black River time there had been deposited, in northeastern Iowa and Minnesota, lime muds that were later to consolidate and form the Platteville limestone. In latest Black River time, when upper Chaumont beds were being deposited in New York and Ontario, there came an uplift somewhere to the north and east of the upper Mississippi Valley that resulted in the stream's carrying to the sea argillaceous muds that were to form the Spechts Ferry shales. By Guttenberg time the land mass to the northeast had become depleted so that most of the clastic materials were limited in their deposition to the areas nearer to the land than the southern part of the present Decorah outcrop, with the result that in its southern extent, the Decorah sediments were for the most part non-clastic; and limestones now prevail. Even in the regions where clastic material was rather abundant, lime muds were being deposited rapidly

[1] W. H. Twenhofel, "Ordovician Strata in Deep Wells of Western Central Kansas," *Amer. Assoc. Petrol. Geol., Bull.*, Vol. XI (1927), p. 49.

[2] E. O. Ulrich, personal communication.

[3] P. E. Raymond, "Trenton of Central Tennessee and Kentucky," *Bull. Geol. Soc. America*, Vol. XXXIII (1922), p. 573.

[4] R. S. Bassler, "Cambrian and Ordovician of Maryland," *Maryland Geol. Survey* 1919, p. 139.

enough so that the beds on consolidation became quite calcareous shales and argillaceous limestones; fragments of fossils make up much of the calcareous content.

Though there was a slight increase in clastic sediments at the beginning of Ion time, the deposition of sediments continued with little interruption through Ion time. At the end of that time, the land mass had been so reduced that the seas were becoming quite clear.

Galena or Prosser time in northeast Iowa began with the deposition of quite pure lime muds on the preceding argillaceous lime muds of the Ion; to the north, argillaceous material was still being carried to the sea. During Ion and Prosser time, the Trenton deposits were forming in New York and Ontario.

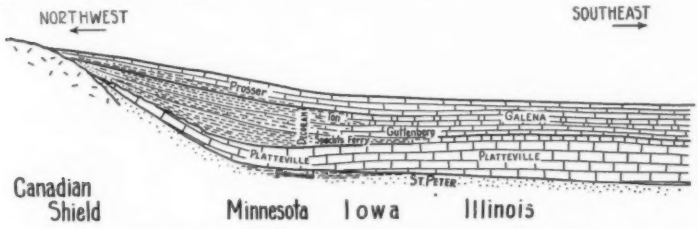

FIG. 12.—Restored section of the earlier Mohawkian deposits from the Canadian shield to the Illinois basin at the end of Prosser deposition.

SUMMARY

The Decorah formation consists of three members. The lowest, the Spechts Ferry member, is composed dominantly of shale. Its fauna, and that of the Guttenberg member above it, seems of the same age as that of the Glenburnie and Watertown members of the Chaumont formation, the top of the Black River in the eastern standard section; the Glenburnie member and Chaumont formation have been defined. The Guttenberg and Ion members of the Decorah formation were limestones in the southern part of their outcrop; these limestones have been irregularly dolomitized. In northern Iowa and Minnesota, the sediments grade into calcareous shales. The Ion member seems of the same age as the Rockland formation at the base of the Trenton group in the standard section. There have been listed other regions in which Decorah faunas have been reported.

POSSIBLE DESERT-BASIN INTEGRATION IN UTAH[1]

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ABSTRACT

The geographic and hypsometric relations of Rush Valley and Tooele Valley, Utah, are described. The forms of the valley floor and peculiar features of Rush Lake and of the alluvial fans of Rush Valley are interpreted as evidences of the probable integration of the drainage of this valley with that of Tooele Valley, the first stage leading toward the coalescence of the basins. Two examples of capture, in the restricted sense, in other parts of the Basin and Range province are cited. The conclusion seems justified that this stage of the arid cycle can now be established inductively and need rest no longer on a purely deductive basis.

INTRODUCTION

Davis long ago presented his deductive discussion of the arid cycle of erosion,[2] and since that time many of the deduced stages have been verified by field observations. However, some stages in the cycle have remained unconfirmed by the finding of actual field examples, and among them that of capture of one desert basin by another.[3] The purpose of this paper is to discuss the relations and certain significant topographic details of Rush Valley and Tooele Valley, Utah, which are believed to furnish an example of such capture, or at least drainage integration (the first stage in basin coalescence) within the arid cycle, and, accordingly, inductive evidence in support of the scheme deduced by Davis.

Tooele Valley, Utah, is a lobe of the drainage basin of Great Salt Lake, projecting southward between the Oquirrh and Stansbury ranges for about 12 miles from the lake. At its southern end South Mountain, a low range of hills formed of Carboniferous quartzites, extends nearly across the depression between the Oquirrh and Stansbury ranges, and, in conjunction with the Stockton Bar, a Lake Bonneville constructional feature,[4] separates the drainage basin of

[1] Published by permission of the Director of the U.S. Geological Survey.

[2] W. M. Davis, "The Geographical Cycle in an Arid Climate," *Jour. Geol.*, Vol. XIII (1905), pp. 381–407.

[3] *Ibid.*, "Peneplains and the Geographical Cycle," *Bull. Geol. Soc. America*, Vol. XXXIII (1922), pp. 596–97.

[4] G. K. Gilbert, "Lake Bonneville," *U.S. Geol. Survey Mon. 1* (1890), pp. 52, 137–38, 145, 228.

Tooele Valley from that of Rush Valley. The floor of Tooele Valley rises southward from the elevation of Great Salt Lake (about 4,200 feet) to 4,900 feet just north of the Stockton Bar. The floor of

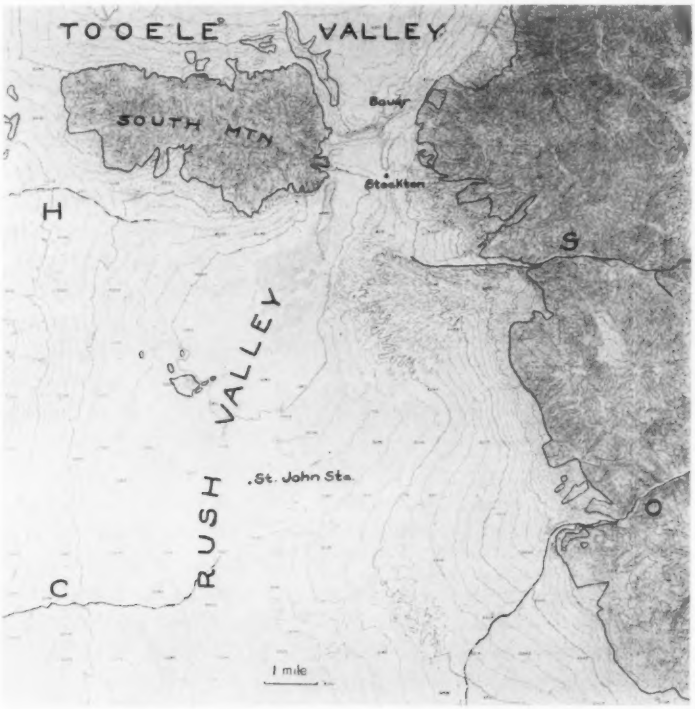

FIG. 1.—Northern part of Stockton quadrangle of U.S. Geological Survey's Topographic Atlas. The heavy lines separate areas of bedrock from those of alluvium. *S*, Soldier Creek; *O*, Ophir Creek; *C*, Clover Creek; and *H*, Hickman Creek.

Rush Valley is about 4,950 feet in elevation at the north end, and rises gradually southward to slightly over 5,000 feet, an elevation it maintains for over 10 miles. The surface features of Rush Valley and the south end of Tooele Valley are excellently shown on the U.S. Geological Survey's topographic map of the Stockton quadrangle, Utah (see Fig. 1).

Although Rush and Tooele valleys are now separate basins, evidence will be presented below which appears to be sufficient to show that this separation has not always prevailed. It is believed that, although these valleys were originally distinct drainage basins, the drainage of Tooele Valley later captured that of the higher-level basin of Rush Valley and that their present separation dates only from the Bonneville stage, when the magnificent bar at Stockton was built.

This conception is based primarily upon the peculiar features of the Soldier Creek fan and Rush Lake. A comparison of the Soldier Creek fan with those of Ophir, Clover, and Hickman creeks—all of them streams of roughly the same size as Soldier Creek—is illuminating.

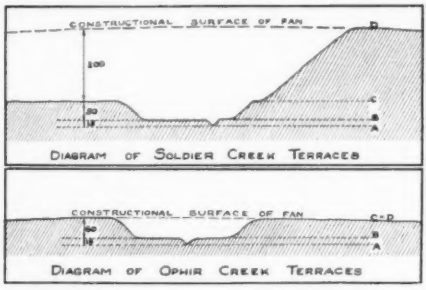

FIG. 2.—Comparison of Ophir Creek and Soldier Creek terraces. *A* is present stream trench; *B*, terraces about 800 feet wide; *C*, terrace of Soldier Creek, a terrace about 2,000 feet wide, not represented on the other fans; *D*, of Soldier Creek fan; and *C* = *D*, of Ophir Creek fan, the original constructional surfaces.

The fans of Ophir, Clover, and Hickman creeks are all smoothly rounded, with relatively small irregularities in contour, except for one incision in each fan which is occupied by the present stream. The incisions made by the present streams in these three fans are decidedly similar. The streams have all trenched their fans in two stages: in the first stage, to depths of 30 to 50 feet, now represented by terraces 800–1,500 feet wide; in the second stage they cut the trenches which they now occupy and which are 10–20 feet below the terraces. The relations are shown diagrammatically in Figure 2.

The fan of Soldier Creek, however, contrasts decidedly with those of the three other important streams in three respects:

First, the intrenchment of Soldier Creek into the fan occurred in three stages instead of only two. The oldest stage is represented by a wide terrace cut about 150–200 feet below the original surface

of the fan. This terrace is over half a mile wide and lies almost entirely on the north side of the present stream. The next stage is represented by a terrace about 800 feet wide, 50 feet lower than the wide terrace just mentioned; hence about 200–250 feet below the original surface of the cone. The present stream has cut into this terrace an additional 10–20 feet. These last two stages are completely analogous to the two-stage intrenchment shown by Ophir, Clover, and Hickman creeks, just described. These features are shown diagrammatically in Figure 2.

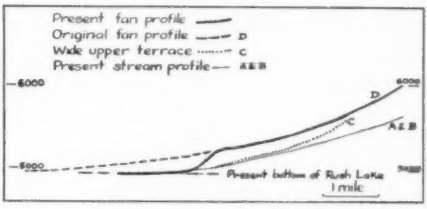

FIG. 3.—Radial profile of Soldier Creek fan

Secondly, not only is the main stream channel of Soldier Creek trenched into the fan, but the entire fan has also been dissected by minor stream channels, and only on the interfluvial ridges is the original convex constructional form of the fan recognizable. Some of these gullies have reached depths of over 100 feet. The contrast between this dissection and the smooth rounding of the constructional slopes of the fan of Ophir, Clover, and Hickman creeks is very great and demands explanation.

A third peculiarity possessed by the Soldier Creek fan alone among the fans of Rush Valley is the convexity of its lower radial profile (see Fig. 3). Such a feature is anomalous in alluvial fans, and, presumably, its cause is to be sought in the cause of the other anomalies of this fan.

Four possible explanations of the features of the Soldier Creek fan have occurred to the writer. These are: (1) oversteepening of the lower slopes of the fan by undercutting by the waves of Lake Bonneville; (2) changes in the regimen of Soldier Creek and the drainage of the fan surface by climatic variation; (3) change of controlling base level of Soldier Creek by earth movements; and (4) drainage modifications by integration of drainage of Rush Valley with that of Tooele Valley.

1. The oversteepening of alluvial slopes by shore erosion of

Lake Bonneville is a very common feature in the Bonneville Basin. It induces gullying of the pre-Lake Bonneville bajada slopes above the Bonneville shore line, and accordingly might be considered an adequate explanation of the peculiarities of the Soldier Creek fan. An example of such oversteepening and consequent gullying may be seen east of Tooele Valley at the extreme north edge of the Stockton quadrangle (see Fig. 1). However, the Bonneville shore line is at 5,250 feet and hence near the top, not the bottom, of the oversteepened part of the Soldier Creek fan. These features are quite clear in the field but unfortunately are not well brought out by 50-foot contours. Furthermore, the shore line is marked by a shallow nip (not deep enough to be shown on the map) on the upper wide terrace of Soldier Creek. It is also marked by small spits and bars which partly block many of the gulches cut in the fan. This shows that the principal dissection of the fan and the development of the high terrace had occurred in pre-Lake Bonneville time, hence that Bonneville erosion can have had no part in it. The fact that the two later stages are incised below the Bonneville shore line proves, for Soldier Creek, and renders exceedingly probable for the other streams mentioned, that the two-stage intrenchment common to all the fans occurred in post-Bonneville time.

2. The hypothesis that climatic changes directly brought about the dissection of the Soldier Creek fan can be briefly dismissed because such effects should be marked on all the other fans in the valley and also because this hypothesis offers no explanation of the oversteepened lower profile of the fan.

3. The hypothesis that the dissection of the fan is to be ascribed to erosion brought about by lowering of base level through earth movements cannot be lightly dismissed. The country is cut up by many Basin Range faults, and there is a considerable possibility that the low area which separates South Mountain from the main mass of the Oquirrh Range is a down-faulted block.

To account for the field facts, it would be necessary to postulate two faults, with a down-dropped block between them—one bounding South Mountain on the east, the other curving about the edge of the Soldier Creek fan and skirting the foothills east of Stockton. The eastern fault would have to die out within a very sharply lim-

ited distance to the south of the Soldier Creek fan. No partly buried fragments of the depressed part of the fan are visible, nor is there any other indication that such faults exist. The curvature of such a fault would have to so nearly coincide with a contour on the constructional surface of the fan as to throw doubt on its existence, especially in view of the fact that subequal retreat of the interfluve parts of the fan would be expected on the hypothesis to be next advanced. Altogether, while a fault displacement could be conceived which would give the features observed, the faults postulated would have to be so peculiar and so rigorously located for concealment, that, to the writer, the probabilities in favor of this explanation seem very slight.

4. A fourth possible way in which the features of the Soldier Creek fan may have been developed is by a drainage change whereby Rush Valley became tributary to the lower-lying Tooele Valley after the construction of the Soldier Creek fan to its original outline. In evaluating this hypothesis, it is first necessary to visualize the present drainage control of the area. This brings us to a consideration of the peculiarities of Rush Lake.

The first of these is its eccentric position within Rush Valley. The valley does not vary more than 100 feet in elevation for over 15 miles to the south, yet Rush Lake is situated at the extreme end of the valley and between two of the largest fans in the valley—a completely anomalous feature in basins of centripetal drainage. Ordinarily playa lakes should be found, while not necessarily central to the basin, at least some distance away from the largest fans.

The second feature is the channel form of the lake. Although its southern end is of typical playa proportions, the northern and deepest part of the lake has a channel form. During periods of low water this becomes very marked in the field, and it was recognized by Gilbert that Rush Lake is a remnant of a pre-Bonneville river draining into Tooele Valley.

If we reconstruct conditions as they existed immediately preceding the Bonneville stage, we then find Rush Valley draining north to Tooele Valley through the gap now closed by the Stockton Bar, we find dissected fans both at Soldier Creek and along the range front east of Stockton, and we find bare rock slopes—pediments—

on the north slopes of South Mountain, where they are smoothly graded, and on the east slopes, where they are less regular. We cannot account for this dissection of fans, for the convex profile of the Soldier Creek fan, and for the anomalous position of Rush Lake unless we consider a still earlier stage.

If we recognize Rush Lake as a stream remnant, it must be conceded that the stream was not present when the Soldier Creek fan was built to its highest form. Reconstruction of this fan on a profile of the type of the Ophir Creek fan puts the 5,050-foot contour of the original constructional surface well over toward the west side of the present playa expansion of Rush Lake. Obviously, the lake would have been crowded to the south in Rush Valley during the period of construction of the fan. Furthermore, projection of the partly dissected pre-Bonneville bajada slopes at the pass between South Mountain and the Oquirrh Mountains shows that they once extended across the pass at an elevation of about 5,100 feet, which would necessitate the separation of Rush Valley from Tooele Valley.

Thus we have an early stage during which Rush Valley had centripetal drainage. Then in some way the drainage was integrated with that of Tooele Valley. A stream cut down at the pass between the two valleys reduced the base level of Soldier Creek, extended headward, and sapped the fan, giving opportunity for dissection. This accounts for the convex profile, the dissection of the fan in three stages instead of merely the two common to the others, and the gullying of the general fan surface. The fans of Clover and Ophir creeks do not coalesce to form a divide in Rush Valley, but the drainage from the south passes between them to Rush Lake. Moreover, these fans show incipient dissection at their lower fringes. These facts appear to furnish further evidence of lowering of the base level of Rush Valley at its northern end through capture by Tooele Valley.

The Bonneville episode intervened before the stream could cut headward enough to lead to severe attack on the more distant fans of Ophir, Hickman, and Clover creeks.

If this picture of events is correct, the next phase of the problem is to account for the integration of drainage between Rush and Tooele valleys.

Three possible modes of drainage integration, other than the faulting already considered, appear possible. One is by the building-up of the Soldier Creek fan till it overtopped the narrows at the present site of the Stockton Bar. This possibility is illustrated in Paradise Valley, Arizona, described by Meinzer and Ellis.[1] This manner of drainage integration would require also a climatic change, because an aggrading stream would not, in the absence of such change, cut down below grade except perhaps at the very crest of an increased declivity, such as would be found upon debouching into Tooele Valley. However, if a long wet period preceded the Bonneville stage, it seems entirely possible to explain all the relations in this way except the bare rock pediments north of South Mountain.

A second possibility is by overflow of an older central playa in Rush Valley during a wet period, perhaps at the beginning of the humid Pleistocene, producing an outlet channel which cut down to the immediately pre-Bonneville topography. This seems equally possible but again leaves the pediments north of South Mountain unconnected with the story.

The third possible way in which the Rush Valley drainage could have been diverted to Tooele Valley is by rock planation and normal head-end extension of Tooele Valley and capture of Rush Valley, the capture having only been well started at the beginning of the Bonneville stage. This manner of capture would accord with the interpretation of the bare rock slopes north and east of South Mountain as pediments.

Decision among the three possible ways in which the coalescence of the drainage of Rush and Tooele valleys may have occurred appears difficult or impossible. Gravel bars and spits at an elevation of about 5,050 feet about a mile northeast of St. John Station and elsewhere in Rush Valley testify to the existence of a water body at this elevation, but whether they are pre-Bonneville or post-Bonneville and are to be correlated with the post-Bonneville shore lines on the south side of Stockton Bar is uncertain. To the writer it appears more likely that they are post-Bonneville. However, since the pre-

[1] C. E. Meinzer, and A. J. Ellis, "Groundwater in Paradise Valley, Arizona," *U.S. Geol. Survey Water Supply Paper 375* (1915), pp. 51–76.

cipitation during the present comparatively arid time is sufficient to maintain a small lake in Rush Valley, it appears certain that in the humid early stages of the Lake Bonneville epoch a much larger water body must have existed in Rush Valley. Such a water body may have overflowed the alluvial divide at Stockton.

The fact that the terrace of Soldier Creek, which formed after the escape of the Rush Valley drainage to Tooele Valley and before the Bonneville stage, is about four times as wide as the post-Bonneville terrace of that stream, implies that the period during which the drainage entered Tooele Valley was several times as long as the total time which has elapsed since the construction of the Stockton Bar, which was built during the Bonneville stage. Inasmuch as the Provo stage of Lake Bonneville alone lasted many times as long as the preceding Bonneville stage, the time during which the drainage went to Tooele Valley was very long measured in years, although geologically brief.

The consideration of the other two possibilities appears likewise inconclusive, inasmuch as only fragments of the precapture bajada surface have survived. However, it is a fairly simple process to reconstruct the surface of the Soldier Creek fan, and according to this reconstruction the writer estimates that the 5,000-foot contour of the fan as originally formed probably passed over the present west edge of Rush Lake and presumably about over the site of the middle of the Stockton Bar. Nevertheless, it is questionable whether this cone was higher than the bajada slope fronting the Oquirrh Range east and northeast of Stockton, thus permitting Soldier Creek to escape to Tooele Valley. Reconstruction of the profile of the bajada slopes on the basis of a few fragments east of Stockton and the general slopes elsewhere along the mountain fronts indicates that such an overflow may possibly have occurred, for the crudities of the method of reconstruction of these short slopes (when applied to the few remnants available) do not permit of reconstruction with a probable error less than 100 feet. An error of this amount would be sufficient to swing the balance either way.

The possibility, therefore, that the capture occurred by the building up of the Soldier Canyon cone till it overtopped the divide at the Stockton narrows must be entertained, but there is strong

evidence that Tooele Valley was encroaching on its headward divide by rock planation in the time immediately preceding the Bonneville stage. The northern slope of South Mountain is bordered by a rock pediment which extends from the level of the Bonneville shore to the 4,900-foot contour. Bed-rock exposures are numerous from bottom to top of the west wall of the valley tongue between Bauer and South Mountain; and a few occur in the east wall, east of Bauer. There can be little doubt that the valley was cutting a pediment headward prior to the Bonneville stage in the manner discussed by Davis,[1] Paige,[2] Lawson,[3] and Bryan.[4] It is highly probable that such headward cutting was an essential condition precedent to the capture, as there is no certainty that the small additional declivity to be obtained by Soldier Creek if it topped the alluvial divide at the Stockton narrows would account, of itself, for the capture of Rush Valley.

A number of modifications of the manner of postulated capture just discussed are possible. It is possible that the increasing humidity just preceding the Bonneville stage led to the formation of a through-flowing stream in Tooele Valley of sufficient vigor to extend into Rush Valley by normal headward erosion.

The writer believes that on the basis of the evidence at hand no dogmatic decision between the three possible manners of drainage diversion discussed is possible. Each reader will decide for himself their relative probabilities. The writer is inclined to attach more weight to the second theory, of overflow of Rush Valley playa, or to the third theory, that of head end extension of Tooele Valley, though he clearly recognizes that the evidence is inconclusive.

However the diversion of drainage occurred, the evidence appears conclusive that integration of drainage has taken place here; and, inasmuch as the Bonneville basin had external drainage only

[1] W. M. Davis, "The Geographical Cycle in an Arid Climate," *Jour. Geol.*, Vol. XIII (1905), pp. 381–407.

[2] Sidney Paige, "Rock Cut Surfaces in the Desert Ranges," *ibid.*, Vol. XX (1912), pp. 442–50.

[3] A. C. Lawson, "Epigene Profiles of the Desert," *Univ. California Publications in Geology*, Vol. IX (1915), pp. 23–49.

[4] Kirk Bryan, "Mountain Pediments, A Discussion of the Erosion of Desert Ranges," *Bull. Geol. Soc. Amer.*, Vol. XXXI, No. 1 (1920), p. 152.

after the shore features (including the Stockton Bar) of the Bonneville stage were formed, this integration occurred within the arid cycle of erosion.

The capture of one closed basin by another, a possible example of which has been described, is by no means unique, though apparently few descriptions have been published. H. G. Ferguson, of the U.S. Geological Survey, has called the writer's attention to a splendid example in the Hawthorne quadrangle, Nevada, where Winwon flat, a high-level desert basin, has just been captured by two separate streams, Nugent Wash, which drains to Gabbs Valley, and Gillis Canyon (misnamed "Wildhorse" on the Hawthorne topographic map), which drains to Walker Lake.

Another excellent example has been brought to the writer's attention by T. B. Nolan, of the U.S. Geological Survey. This is furnished by an area of about 150 square miles between Charleston and Point of Rocks, in the Las Vegas and Furnace Creek quadrangles, Nevada and California. This area was formerly tributary to Indian Springs Valley but has been captured by a tributary of Amargosa River. Evidence for this capture is clear not only from the surface features but from the rock composition of the dissected alluvium, both showing that the drainage was formerly tributary to Indian Springs Valley.

The capture of one closed basin by another is probably a rare occurrence, especially in the northern part of the Basin and Range province, where orogenic activity is still progressing. Drainage integration has probably chiefly occurred through processes of aggradation or overflow of the higher basin; hence not true capture in the restricted sense. The ultimate results of the processes, however, are identical and lend strong support to the deductions of Davis regarding the arid cycle.

The writer gratefully acknowledges the helpful discussion of the subject of this paper by Messrs. Campbell, Meinzer, Ferguson, and Nolan of the U.S. Geological Survey, without, of course, implying that the opinions herein presented meet with their approval.

THE STRUCTURES AND BATHOLITHS OF FRENCH RIVER AREA[1]

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ABSTRACT

The area about the outlets of the French River serves as a connecting link between the Huronian area proper and the regions east of Georgian Bay containing the Grenville and Laurentian rocks. The major structures of these areas are connected in French River area by a unifying but peculiar major fold. It is fan shaped with its apex to the north, to which converge anticlines, synclines, and fault lines. The batholiths conform to the country gneisses of this structure, and appear to bear very close relationships to the gneisses themselves. The gneisses are ultimately of sedimentary origin, and together with the associated batholiths appear to illustrate the conditions which prevail at great depth during times of major diastrophism, and perhaps to indicate how batholiths are formed. In any case the batholiths are subordinate in shape and distribution to the structure of the country gneisses, the major structure of the area.

INTRODUCTION

Northeast of Georgian Bay lies Lake Nipissing, the overflow of which pours westward into the Great Lakes, constituting the historic route of French River. French River pursues an irregular and branching course through lakelike expansions, rapids, and falls, and finally uniting with the waters of Wahnapitei and Murdock rivers from the north, and with those of Pickerel River from the southeast, it splits again into five distributaries by which its waters reach Lake Huron. The complicated groups of falls, rapids, and tortuous channels which make up the outlets of French River border the extreme northeastern corner of Georgian Bay, a geographical corner which accords to a notable geological flexure. For present convenience this locality and its environs will be called the "French River area." It includes the mouths of the French River, for about 20 miles the district west to Killarney, to about equal distances northward to Trout Lake and southeast to Naiscoot River, and for about 15 miles to the east of French River outlets. The region which is indicated on the accompanying map (Fig. 1)[2] is about 50 miles wide from north to south, and about 60 miles long from east to west.

[1] Published with the permission of the Director of the Geological Survey of Canada.

[2] Cf. "French River Sheet," *Geol. Survey of Canada Sheet 125* (1897).

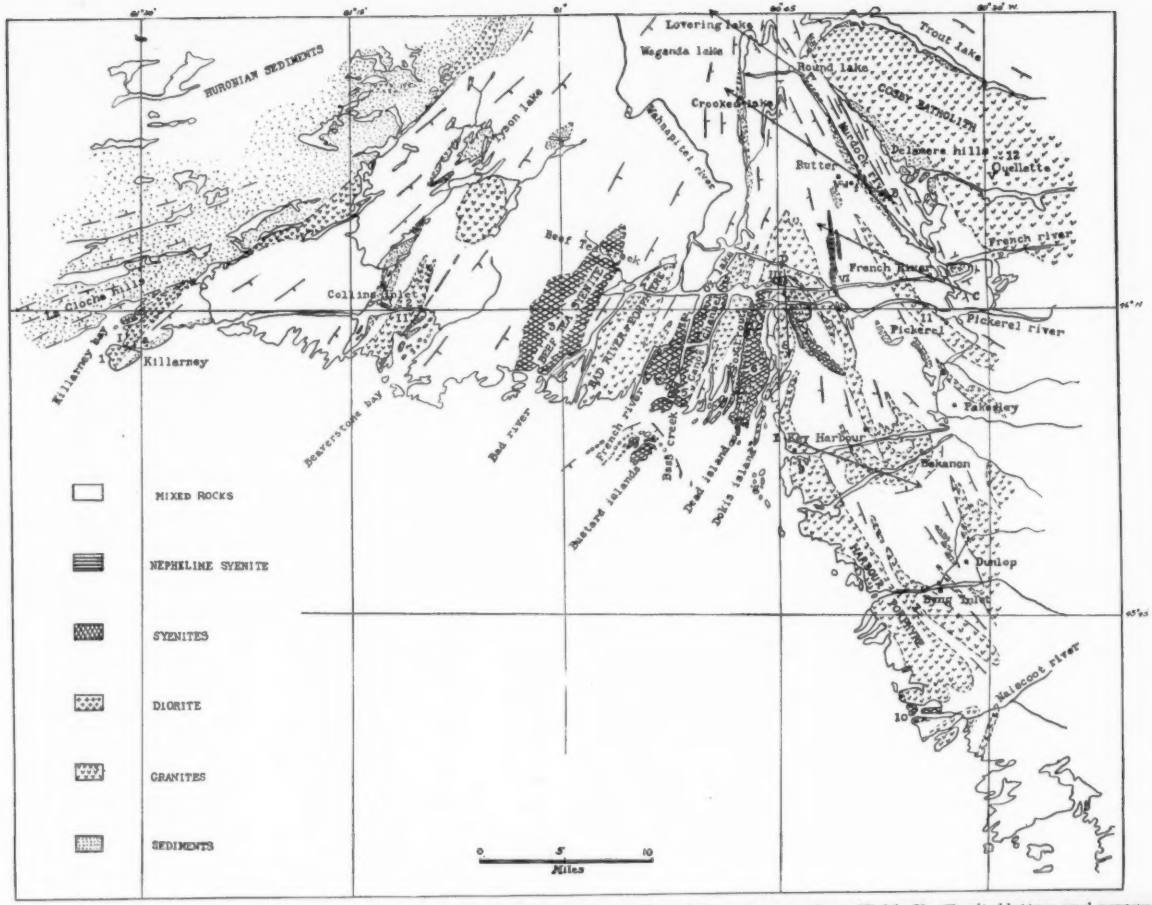

FIG. 1.—French River area. Lower case letters place chemical analyses of banded country gneisses (Table I). Capital letters and arrows

French River lies between two well-defined geological provinces, the North Shore of Lake Huron on the west and the Haliburton-Bancroft area to the east. The general structure of these two provinces is generally thought to be dissimilar, but the French River area lying between them serves admirably as a link to connect them as parts of a larger geological district.

The general trend of the structure along the north shore is southwest-northeast; the general trend of the structure in the neighboring area, bordering the eastern shores of Georgian Bay, is northwest-southeast, or practically at right angles to that of the former. This striking discordance in general structure has been noted by many others, and has been partly responsible for the general acceptance of the notion that the north shore and the Haliburton-Bancroft area, which lies beyond the French River area to the east, are geologically distinct. The mutual independence of these regions is also indicated by their apparent dissimilarity in geological composition. On the north shore the rocks are mainly definite and characteristic sediments, the original Huronian formations, which lie unconformably upon older greenstones and granite. They are cut by abundant diabase intrusions, and are intruded by a younger granite, the Killarnean.[1] The Haliburton-Bancroft area is characterized by the Granville series of sedimentary gneisses, including the famous crystalline "limestone," and by the Ottawa gneisses, which are penetrated by nepheline syenites, by basic intrusives, and by granitic batholiths called "Laurentian." In spite of the apparent unlikenesses of the rock formations in these two regions it appears that there is not actually any notable structural discordance between the two regions, but rather that they are complementary members of a great structure common to both, using the French River area as the most important link.

THE MAIN STRUCTURES

The most easterly structure of the Huronian rocks of the north shore is shown both by Bell[2] and by Collins[3] to end very abruptly

[1] W. H. Collins, "The Age of the Killarney Granite," *Geol. Survey of Canada Mus. Bull. 22* (1916).

[2] Robert Bell, "French River Sheet," *Geol. Survey of Canada* (1898).

[3] W. H. Collins, *Geol. Survey of Canada* (1920), Map 152A.

FIG. 1.—French River area. Lower case letters place chemical analyses of banded country gneisses (Table I). Capital letters and arrows

against a mass of granite and granite-gneiss in a region of great folding and faulting of the Huronian sedimentary rocks. A continuation of this type of structure in a region of granite and gneisses between Killarney and the western outlets of the French River has been described elsewhere by the present writer.[1] Detailed mapping on a scale of 2 inches to a mile has now been continued not only to the east of the French River outlets, but also along the eastern shores of Georgian Bay for about 30 miles south of Key Harbour, and into the area east of Parry Sound. A much clearer idea of the controlling structure has now been developed. It is apparent that the lines of faulting and the axes of the main folds converge toward a central point near Wanup, about 20 miles southeast of Sudbury. These lines form a pattern like the spokes of a portion of a wheel, or like the lines of a fan, and the anticlines and synclines, some of which plunge toward the center and some away, resemble, as Dr. Collins suggested, the wrinkles in a bent coat-sleeve. On the accompanying map (Fig. 1) one may note the general trend of the structures. Northwest of Killarney the sediments strike about N. 60° E.; at Killarney the general bearing of the structures is about N. 45° E.; farther east at Collins Inlet it is about N. 15° E.; and at Dead Island and the Fox Lake outlet of the French River it is about north and south. Farther east the trend is west of north; at Key Harbour it is about N. 10° W.; at French River station it is about N. 30° W.; and in the northeast at Trout lake it is about N. 60° W. These places illustrate the general swing of the structural trend from 60° E. to 60° W. of north.

TOPOGRAPHIC INDICATIONS OF THE STRUCTURES

On the geographical maps the general structure trends are indicated by the shapes and distribution of the lakes and water courses, such as Tyson Creek and associated lakes, and the remarkable curved lines of Crooked lakes, Waganda, Lovering, and Round lakes, together with their continuation along the Canoe Channel to the southwest and along the Murdock River to the southeast. All the outlets of the French River conform to the western flank of this syncline, and many of the cross-cutting channels and curious strings

[1] *Jour. Geol.*, Vol. XXXII (1924), pp. 333–35, and *Amer. Jour. Sci.* (5th ser.), Vol. XI (1926), pp. 165–73.

of lakes south and east of Murdock River are localized by the eastern limb of the syncline. The eastern shore of Georgian Bay itself follows the same general control.[1]

AREAL GEOLOGY OF THE MAIN STRUCTURES

Most of the water lines are controlled in general by the bedding of sedimentary gneisses, which are associated with quartzites, conglomerates, and amphibolites, correlated with the Bruce and Cobalt series of the Huronian division. The same group of sedimentary gneisses may be followed along the strike, marking the trace of the major synclinal fold, for more than 50 miles.

The geological map (Fig. 1) shows the distribution of sedimentary formations indicating the nature of the major structure. Furthermore, the distribution of these rocks of obviously sedimentary character, chiefly quartzites, gives a meaning to the associated, banded country gneisses.[2] These gneisses look like igneous rocks in hand specimens, and chemical analyses (Table I) show that they are essentially the same in composition as many alkaline plutonic rocks;[3] however, inasmuch as they may be traced both across and along the strike into conglomerate and quartzite rocks they are concluded to belong to the category of mixed rocks or migmatites.[4]

RELATION OF BATHOLITHS TO STRUCTURES

Within these country gneisses certain areas have been mapped (Fig. 1) as plutonic rocks, nepheline syenite, syenite, diorite, and granite, but the larger-scale manuscript map on which the field work has been compiled shows many more subdivisions. The masses of plutonic rock are in general small, less than 15 miles long and less than 5 miles wide, and they are separated from one another by strips or by wide areas of the country gneisses and sediments. Each of the

[1] Cf. F. D. Adams and A. E. Barlow, *Internat. Geol. Cong. Guide Book 2* (1913), p. 13; and E. M. Kindle and L. D. Burling, *Geol. Surv. of Canada. Mus. Bull. 18* (1915), p. 7.

[2] The general structural trends of these gneisses are shown on the "French River Sheet" (*Geol. Survey of Canada Sheet 125*), by Robert Bell. In general they agree with those shown by the present writer.

[3] According to the American classification, these rocks correspond chemically to the following groups: *a*, *f*, and *g*, alaskose; *c*, *d*, and *e*, liparose; and *b*, tonalose.

[4] J. J. Sederholm, *Geol. Com. Finland Bull. 58* (1923), and T. T. Quirke, *Bull. Geol. Soc. America*, Vol. XXXVIII (1927), pp. 753–70.

masses is distinct from its neighbors. The coarse granite at Killarney is dark salmon colored, that which cuts the sediments to the north

TABLE I

CHEMICAL COMPOSITION OF COUNTRY GNEISSES

	a	*b*	*c*	*d*	*e*	*f*	*g*
SiO_2	76.71	54.00	69.00	71.06	71.70	76.80	71.28
Al_2O_3	12.87	20.65	14.95	13.60	13.22	11.58	13.35
Fe_2O_3	1.12	4.33	3.41	1.28	1.34	.50	.70
FeO	.31	5.05	2.34	2.08	1.87	.86	1.57
CaO	.40	7.20	1.60	1.70	1.48	.84	1.56
MgO	.38	3.11	.73	1.62	1.13	.47	.93
K_2O	6.04	1.74	3.86	3.98	4.44	6.04	6.09
Na_2O	2.05	3.52	4.07	3.80	4.40	2.41	2.96
H_2O plus	.25	.42	.19	.38	.13	.19	.48
H_2O minus	Nil	.05	.10	.....	.....	.....	.11
TiO_2	.15	N.d.	N.d.	.34	.17	.05	.74
MnO	.....	.....	.....	.04	.02	Tr.	.05
P_2O_5	.05	N.d.	N.d.	.05	.01	.....	.23
BaO	.....	.....	.....	.....	.....	.....	.16
S	.14	.....	.....	.....	.....	.....	.08
Cl	.....	.....	.....	.....	.....	.....	.01
CO_2	Nil	.27	.16	.20	.10	.49	Nil
	100.47	100.34	100.41	100.15	100.01	100.23	100.27

a) Banded gneiss, east of Killarney village on Killarney Channel. About intermediate in composition between massive Killarney granite and well-bedded Huronian quartzite, a transition gneiss. (R. C. J. Fabry, analyst.)

b) Banded gneiss, east of Rutter. A dark-colored layer in the Gowganda formation, probably originally a fine-grained silt rock. (M. F. Connor, analyst.)

c) Banded gneiss, east of Rutter. A pale-pink sillimanite gneiss which is an altered conglomerate of Gowganda age, probably originally a typical "slate conglomerate." (M. F. Conner, analyst.)

d) Banded gneiss, east of Rutter, similar to *c* but lacking the evidence of a conglomeratic origin. Several hundred feet stratigraphically below *c*, but also part of the Gowganda formation. (William Gerrie, analyst.)

e) Banded gneiss, near west bank of Murdock River, east of Rutter. A highly altered conglomerate member of the Serpent formation. (William Gerrie, analyst.)

f) Banded gneiss, near same locality as *e*, but stratigraphically lower and separated from it by a band of quartzite. It is an altered member of the Serpent formation. (William Gerrie, analyst.)

g) Banded gneiss, Special Islands, southwest from Key Harbour. A gneiss apparently of sedimentary origin, but with invasive boundaries and of undetermined correlation. (R. C. J. Fabry, analyst.)

is chiefly pale gray, and the granite gneiss at Collins Inlet is finer grained and dull red. The next mass eastward is known as the

"Beef Tea batholith," a dark-gray syenite high in magnetite and hornblende, followed by the Bad River batholith, a pink, coarse granite porphyry. Farther east is the Bass Creek batholith which forms part also of the Bustard Islands. It is a dark-gray rock grading from quartz syenite to granodiorite. East of this batholith is a series of thin sheetlike masses which lies within the banded gneisses. These masses include a curious red-brown hornblende and garnet-bearing syenite, named the "Dead Island syenite"; a pale-gray diorite with streaks of hornblende and garnet generally parallel to the inclosing banded gneisses, named the "Pickerel diorite"; and a highly quartzitic red-granite porphyry named the "Dokis granite." This granite porphyry seems to be closely related to a long narrow strip of gray and dark-red syenite porphyry, named the "Harbour batholith," which stretches along the eastern shore line of Georgian Bay for about 30 miles, everywhere less than 5 miles wide. East of the Harbour porphyry, between Key Harbour and the Indian village of Bekanon, is another granite intrusion which varies in mineral composition from syenite to alaskite. This is a stringy, ribbon-shaped mass, sharply twisted at the south end within a minor structure. It extends northward around the nose of the syncline, and appears to continue on the west flank of the main structure in a granitic band between the Bass Creek batholith and the Dead Island syenite. It may be called the "Bekanon granite." East of the northern extension of this mass lies a strip of nepheline and associated syenites. And in the northeastern part of the area lies a large mass of granite and syenite porphyry named the "Cosby batholith." South of the Cosby batholith, northeast of the Bekanon batholith, and nearly parallel to it, is another strip of syenitic rock, called the "Pakesley batholith," a remarkable moonstone porphyry in some parts, and a strange olive-drab syenite in others. In the southeastern part of the area is a coarse granite porphyry mass named the "Dunlop porphyry," and at the mouth of Naiscoot River there is a curious pale-gray syenite which looks in the field like the Pickerel diorite. The foregoing igneous masses have a uniform composition generally along directions which are parallel to the strike of the inclosing country gneisses, although neighboring masses

differ considerably in color, in texture, and in some cases in mineral composition from one another.

The plutonic masses are generally lens or thin wedge shaped,[1] with the small ends pointed toward the convergence of the structural lines. It may be assumed that the *locus* of convergence was the region of most intense compression, and that the greatest relief from compression was in the outer regions of the structural fan. It is worthy of note, however, that these intrusive lenses are inclined to widen along the axial region of the great syncline, indicating that intrusion and folding were closely connected in origin. For instance, the Pickerel diorite and the Bekanon batholith widen at the axis of the fold and fray out along its flanks, giving rise to saddle-shaped areas on the map. Similarly, the Dokis Island granite swells out into a spear-head shape in a corresponding position, pinching out farther south into a narrow shaft at the place of cross-folding near Dokis Island.

These structural relationships indicate that the major control is due to the tectonic conditions, and that the plutonic masses are there as it were on sufferance. The igneous masses occupy the apexes of folds, the regions of least compression, in much the same manner as the incompetent members of a folded series commonly swell into thickened lenses in similar positions. However, toward the area of extreme compression in the north-central part of the area igneous intrusions seem unimportant. Igneous intrusion was here evidently subordinate to tectonic control.

STRUCTURES SHOWN BY AERIAL PHOTOGRAPHS

The reality of these structures is illustrated by certain photographs[2] taken by the Royal Canadian Air Force at the request of the Director of the Geological Survey of Canada. These pictures were not available to the writer until after the field geology had been done, nevertheless they serve to illustrate part of the structures indicated above and on the map.

The five localities illustrated are indicated on the map by arrows

[1] Cf. R. T. Chamberlin, *Jour. Geol.*, Vol. XXIII (1925), p. 792.

[2] Published here with the permission of the Department of National Defense of Canada.

and letters. Photo A (Fig. 2) was taken with a general northwestward direction of view and shows in the foreground the eastern flank of the main syncline, along the edge of which runs the Canadian Pacific Railway. To the left is a series of curving beds indicating the nose of the syncline, and in the central background the V-shaped lake marks a subsidiary anticline within the main structure. The larger narrow lakes farther in the distance mark the western flank of the main syncline, and they indicate on the west side the position

FIG. 2.—Photo A

of the same beds which outcrop in the immediate foreground of this picture.

Photo B (Fig. 3) was taken south of the locality of Photo A, and it shows the continuation of the same formations southward along Murdock River. At the highway bridge and farther to the left, beds of quartzite gleam white against the general dull background made up of gray and pink conglomerates and gneisses. The chemical analyses in Table II were made from samples collected along the road from the well-bedded gneisses which lie between Murdock River and the clearings of Rutter station which show in the central background. The sedimentary appearance of these beds is well shown. In the field the formations here represented were correlated with

the Serpent, Espanola, and Gowganda formations of the Huronian series.

Photo C (Fig. 4) shows the direct continuation of the beds shown in Photo B southward to the French River. The smoke shown rising from the southern end of a little lake in the left background is near the nepheline syenite. The picture shows the French River Bungalow Camp, the gorge of the French River, and the gleam of Grand Ricollet Falls near the left margin of the plate. The rocks shown in the foreground are still well bedded, but their general westward dip

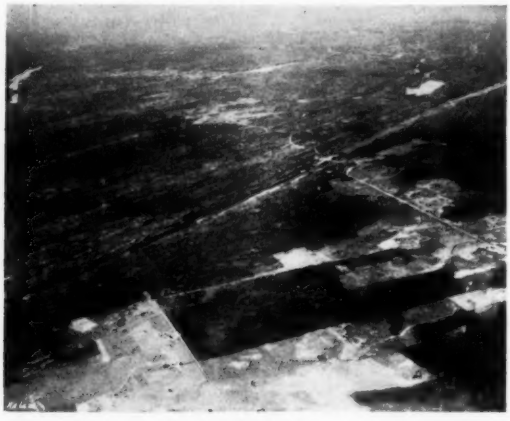

FIG. 3.—Photo B

is steeper than at Rutter, and examination in the field shows them to be much more massive in texture. Nevertheless, these bands have been traced individually for many miles along the strike from place to place; they are the same beds as those mapped at Rutter, and of sedimentary origin.

Photo D (Fig. 5) was taken over the central part of the main syncline, facing south. The river closest in the foreground is French River, about 9 miles west of French River camp. Nearly parallel and about a mile farther off than French River is Pickerel River, and beyond that to the right is the upper end of the eastern outlet. Veering to the left in the central background is a string of lakes parallel in direction to the strike of quartzites and country gneisses.

To the right also, down the eastern outlet the curving lines of well-banded country gneisses mark the trace of the southward-plunging syncline. The pale rock in the foreground is part of the Pickerel diorite in its widest part; to the southeast it tongues out into the banded gneiss, but widens again still farther south in the land masses between the eastern outlet and the Fox Lake outlet on the western side of the syncline.

Photo E (Fig. 6) transfers the scene to the northern part of Harbour batholith on which the docks of Key Harbour are built.

FIG. 4.—Photo C

Here one notes the absence of definite structural character in the shape of the rock outcrops, in the shape of the watercourses, or in the distribution of the forest covering in the right foreground. The eastern contact, however, lies along the narrow wooded valley running nearly due south, from near the center of the lower margin of the picture to a narrow lake at the right-hand border of the view. The main structure of the country gneiss to the east (left-hand side) runs parallel to this line of contact, but cross-jointing almost at right angles gives a grating appearance to the areas of bare rock bounded by lines of vegetation, particularly in the left foreground. On the other hand, the shape of the bare outcrops in the extreme right foreground, uncontrolled by any definite system either of

banding or of jointing, is characteristic of the appearance of the plutonic masses as shown in airplane photographs. Near the contacts the banding and cross-jointing so characteristic of the country gneisses commonly persists in the batholiths, becoming less definite at greater distances from the borderlands, and being quite indistinguishable in the porphyritic areas. The system of joints at right angles to each other appears to have been of great influence in determining the location of the water routes. In photo E, however, the course of Key Inlet seems to be out of accord with both of the jointing systems.

FIG. 5.—Photo D

MUTUAL RELATIONSHIPS OF THE BATHOLITHS

Mineralogical analyses of most of the plutonic masses follow in Table II, and chemical analyses of some in Table III. Almost at a glance one may note the apparent similarity in composition between Nos. 1, 2, 4, 8, 9, and 12, Table II, and between Nos. I, II, IV, and V, Table III. There is also much in common between Nos. 3, 5, 6, and 11, Table II, and a more distant relationship between this group and Nos. 7 and 10, Table II, but there seems to be no relationship between any of these and No. VI, Table III. In other words, the following masses are similar, and chiefly granitic porphyries of the Killarney type: Killarney, Collins Inlet, Bad River, Dokis Island,

Harbour, and Cosby batholiths according to the mineral and chemical analyses, to which may be added the Dunlop and Bekanon masses on the basis of field examination. In another more distinctly syenitic group are the following: Beef Tea, Bass Creek, Pakesley, and Dead Island batholiths; perhaps this group is distantly related to the Pickerel diorite and the Naiscoot syenite, but none of these is apparently related to the French River nepheline syenite.

FIG. 6.—Photo E

CONNECTIONS BETWEEN BATHOLITHS AND GNEISSES

From stratigraphic and structural field evidence in the district about Killarney it appears reasonable to conclude that many thousands of feet, perhaps as much as 5 miles, of overlying rock has been eroded from the batholithic area. This French River area accordingly appears to contain plutonic masses of much more than the usual depth of solidification. Consequently we may expect to find conditions somewhat out of the ordinary. Intensity of intrusive activity might be expected because of the conditions of deep burial, and it is indicated by the profound character of the regional metamorphism. The country gneisses themselves, banded, stratified, and persistently solid though they appear to have remained, are nevertheless of a mineralogical and chemical character almost if not

quite indistinguishable from that of igneous rocks.[1] One is led, therefore, to seek stratigraphic associations to fit chemical relationships. It appears evident that some of the granitic and porphyritic masses occupy fault lines, and that they all lie within paragneisses which

TABLE II

MINERAL COMPOSITION OF INTRUSIVE MASSES—ROSIWAL PETROGRAPHIC ANALYSES

	1	2	3	4	5	6	7	8	9	10	11	12
Quartz	28.30	24.60	12.55	19.96	5.25	11.60	.....	25.90	30.30	10.35	7.60	30.36
Orthoclase	63.27	33.36	28.00	58.20	9.30	46.90	.....	49.90	62.00	3.05	20.35	21.13
Oligoclase-albite		29.60	28.30	6.92	61.80	19.19	.....	21.74	.....	61.36	47.00	41.70
Oligoclase-andesine	.....	.....	.....	.....	.....	.....	81.80	.....	.....	.....	.....	.....
Amphibole	.....	7.00	25.63	7.35	14.00	20.88	2.85	.....	.63	21.60	23.15	5.87
Biotite	5.63	.....	4.17	1.29	7.11	.....	11.30	.....	5.70	1.47	.94	.....
Muscovite	.96	.....	0.33	.....	.....	.....	.....	.....	.....	.....	.....	.....
Titanite	1.57	.....	.....	0.48	0.65	0.04	.....	1.86	.....	1.63	0.60	.....
Magnetite	.27	2.92	1.02	5.78	1.17	1.39	0.42	0.60	1.25	.....	.....	6.96
Apatite	.....	.....	.....	.....	0.20	.....	0.19	.....	0.29	0.54	0.36	.....
Garnet	.....	.....	.....	.....	0.52	.....	4.05	.....	.....	.....	.....	.....

NOTES TO TABLE II

1. Killarney granite, collected at the west end of Killarney Channel. In this analysis orthoclase and plagioclase are not differentiated. Rock is coarse grained and salmon colored.
2. Collins Inlet gneissic granite, collected ½ mile east of Collins Inlet village along the inlet. Rock is medium grained and dull red in color.
3. Beef Tea batholith, quartz syenite. Collected west of Bad River near the mouth of Beef Tea Creek. The rock is medium grained and dark gray in color.
4. Bad River batholith, granite. Collected east of Bad River, near the main east-west channel of French River. The rock is a coarse porphyry and dull red in color.
5. Bass Creek batholith, syenite. Collected near the outlet of Bass Creek. The rock is medium grained, medium to dark gray in color.
6. Dead Island batholith, syenite. Collected on Pickerel River. Rock is coarse grained, ruddy brown on weathered surfaces, and olive drab on fresh exposures.
7. Pickerel batholith, diorite. Collected near Canadian National Railway bridge on French River. Rock is coarse grained, pale gray in color, and on weathered surfaces almost white.
8. Dokis batholith, granite. Collected south of Dead Island, west of Key Harbour. Rock is coarse grained and in most places porphyritic; it is dull red in color.
9. Harbour batholith, granite and syenite. Collected near Key Harbour. Rock is coarse grained, in some places extremely coarse; it varies from dull gray to pale pink in color.
10. Naiscoot intrusion, syenite. Collected at northern outlet of Naiscoot River. Rock is coarse grained and pale gray in color.
11. Pakesley batholith, oligoclase syenite. Collected near Canadian Pacific Railway, ½ mile south of Pickerel station. Rock is coarse moonstone porphyry, pale pink in color.
12. Cosby batholith, granite. Collected near Ouellette, Cosby Township. Rock is coarse porphyry, dull red in color.

appear to have originated as siliceous clastic rocks, chiefly quartzites and "slate" conglomerates. Of these the following are known to occupy the position of, or to border, quartzites: Killarney, Collins Inlet, Bass Creek, Bekanon, Dead Island, Dunlop, and (in part) Harbour batholiths. The following in whole or in part appear to have similar relationships to slate conglomerates: Pakesley, Bass

[1] They are prevailingly alaskose and liparose in chemical classification.

Creek, Bekanon, and Harbour batholiths. Nearly all the syenites and the diorite lie well within the central part of the main syncline. They outcrop on both flanks and around the nose of the structure, dipping with the quartzites and banded gneisses where they out-

TABLE III

CHEMICAL COMPOSITION OF INTRUSIVE MASSES

	I	II	III	IV	V	VI*
SiO_2	71.36	68.25	56.18	64.41	69.70	55.90
Al_2O_3	14.88	14.53	23.26	13.76	16.85	22.12
Fe_2O_3	.90	1.29	.81	1.22	2.73	.96
FeO	1.22	2.64	2.27	5.22	1.10	4.33
CaO	1.77	.99	8.55	3.57	1.20	.44
MgO	.56	1.04	1.59	1.47	.62	.37
K_2O	4.52	5.69	1.59	4.70	3.66	6.42
Na_2O	3.23	3.02	4.61	3.20	4.12	8.35
H_2O plus	.81	.....	.56	.40	.20	.57
H_2O minus	Nil	.....	.01	.....	.10	.....
TiO_2	.18	.58	.27	1.64	N.d.	.05
MnO	.09	.13	.05	.20	Tr.	.14
P_2O_5	.30	.21	.20	Nil	N.d.	.....
BaO	Nil	.....	.05	.....	.....	.....
S	Tr.	.....	.....	.....	.....	.....
Cl	.02	.....	.02	.....	.....	.....
CO_2	Nil	.....	.....	.....	.15	.67
	99.84	98.67	100.02	99.94	100.43	100.32

* *Contributions to Canadian Mineralogy* (1926), p. 6; "University of Toronto Studies, Geological Series," No. 22.

I. Killarney granite, west end of Killarney Channel. (R. C. J. Fabry, analyst.)
II. Collins Inlet gneissic granite, near village of Collins Inlet. (F. F. Grout, analyst.)
III. Pickerel diorite, near Canadian National Railroad bridge over Pickerel River. (R. C. J. Fabry, analyst.)
IV. Harbour granite, near Key Harbour. (R. C. J. Fabry, analyst.)
V. Cosby porphyry granite, near Ouellette, Cosby Township. (M. F. Connor, analyst.)
VI. French River nepheline syenite, French River. (H. C. Rickaby, analyst.)

crop on the western flank of the fold. Either they are thin, sheetlike members inserted as layers between the banded gneisses, or else they are replacements of other rocks originally in their position. As for the nepheline syenite, it appears to belong rather to such sporadic and irregular phenomena as the pegmatites than to the porphyritic plutonic masses. It seems to have little structural or mineralogical relationship to the other masses mentioned.

SOURCES OF THE BATHOLITHS

The implication of all these things appears to be that here we have a chance to examine the bourne whence plutonic invasions arise. In this case coarse-grained porphyritic masses have come into being associated with severe tectonic movements. The granitic rocks appear to be replacements of sedimentary rocks. The phenocrysts in some cases certainly have grown within gneisses which still are easily distinguishable as sedimentary rocks, and these gneisses grade into masses which are so exclusively porphyritic that no trace of other structure or texture remains visible. None of the porphyritic masses shows more than obscure indications of having undergone movement as liquid masses or of having transmitted such pressures to their inclosing rocks as usually are indicated about the margins of irruptive masses. Nevertheless, some of them, particularly Killarney and Collins Inlet masses, follow fault lines, and that circumstance in itself suggests that these masses may have arisen from still greater depths, perhaps from some very deeply buried magma chamber into their present positions. The question then arises as to whether we would recognize such an original magma chamber if it were uncovered by erosion, and would it differ in appearance and in origin from the remaining batholiths exposed in French River area? The writer is inclined to believe that these separate, apparently disconnected streaks of plutonic rock represent the sort of thing from which greater batholiths are supplied. They may illustrate an early stage in the development of batholithic invasion. Provided they were, or were about to become, liquid at the same time, under favorable tectonic coercion they might have supplied enough material to coalesce into one or more large batholiths nearer the surface of that time. Apparently the development of a general batholithic invasion did not take place in this case, although the conditions may have approached nearly to that stage. Porphyries were formed, potentially irruptive rocks, which did not move from the place of origin. On the other hand, some material, apparently minor in quantity, actually moved under favorable structural conditions and may be found today invading relatively slightly altered sediments about the eastern part of Lake Panache, Killarney Bay, and elsewhere on the north shore. However, about French River the

batholiths were still-born; they died where they came to birth. Nevertheless, in their shapes and distribution they indicate pointedly the major control of the area, and serve to emphasize the truly regional extent and influence of the great fanlike structure which here links east to west.

SUMMARY

The general structure of this region is indicated by the distribution of the sediments, which are everywhere parallel in strike to the country gneisses. From the structure of these two groups of rocks that of the region has been described. This structure is further indicated by the shapes and distribution of the waterways and of the plutonic masses. The character and composition of the plutonic rocks and of the country gneisses leads to the conclusion that they are closely linked in origin as well as in structure. Indeed, it is suggested that this area affords an idea of the regions from which plutonic invasions are supplied. The structure here assigned serves not to separate the Huronian area from the districts characterized by Grenville and Laurentian rocks, but it acts as a tie between the two, linking the apparently discordant trends of the contrasted regions into a reasonable unity.

ACTIVE FAULTS NEAR WHITEBIRD, IDAHO

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ABSTRACT

Fissures which developed near Whitebird, Idaho, in November, 1927, were under observation until November, 1928. There are two larger displacements which are essentially parallel, and several smaller ones, all of which occur in a gently sloping terrane made up of lava flows and interbedded sediments. One of these faults has a known length of 8,200 feet, and an inferred length of 13,600 feet. Displacement was measured from time to time by means of a series of stakes set on each side of the fissures. A horizontal movement of 7.35 feet and a vertical movement of 3.5 feet represent the amounts of displacement in a year's time. The fissures may border gigantic landslides, or may be gravity faults, but a study of the evidence points to the latter.

INTRODUCTION

The area lies in T. 28 N., R. 1 E., 4 miles east of Whitebird, about 26 miles southwest of Grangeville, and 155 miles south of Moscow, Idaho, on the North-South Scenic Highway.

The faults were first observed by the writers in March, 1928, during a visit to a fossil-collecting ground near Whitebird. The "cracks," as they are locally called, occur within a mile of the fossil locality and attracted attention by the displacement in the road. A brief reconnaissance of the area on March 24 and 25, 1928, established the nature, significance, and active state of the faults.

Numerous measurements were made and several series of stakes were set, in order to determine the amount and direction of future movement. This unusual activity in an otherwise unpopulated and inactive region started many rumors which emanated from Whitebird and Grangeville as press stories crediting the faults with gigantic proportions, and many peculiar and unusual properties including gas emanations and oil seeps. Resulting from these press stories several thousand curious people visited the locality in the next few weeks. The area lies on the scenic Whitebird switchback grade, and fear was expressed by many that the famous highway would be destroyed by the movement.

Photographs were taken on April 25, 1928, and on several other

visits, showing the displacement in the road and other characteristic features. The examination was renewed on May 25 and 26, 1928, and a detailed plane-table map was made of the fault pattern and topography on a scale of 600 feet to the inch (see Fig. 1). New measurements compared with the original ones showed the amount and direction of movement since the last measurements. Another visit was made on June 23, 1928, and additional data were secured on the progress of the movement. Subsequent visits to the area on August 30, 1928, and November 13, 1928, extended the investigation over a sufficient length of time to permit of several generalizations.

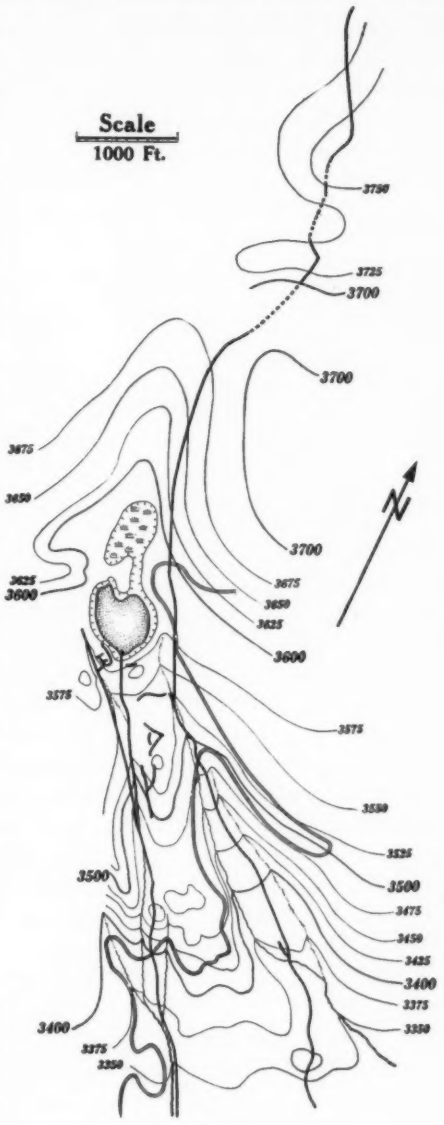

FIG. 1

TOPOGRAPHY

The greatest relief in the disturbed region is 400 feet, but an escarpment rises 800 feet higher near the north

end of the major fracture. The faulted sector is not particularly rugged, or rough, and shows few characteristics of "landslide topography," as can be seen from the accompanying illustrations. Some of the topography suggests, however, that the area between the two major displacements has experienced similar movements previously. In places it is slightly lower than the sectors to the immediate east, or west, and is roughly bounded by depressions temporarily occupied by streams (see Fig. 1). The fall of the surface slope along the strike of the faults is about 1 foot vertically to 35 feet horizontally.

FIG. 2.—Showing offset in highway caused by horizontal displacement in No. 1 fault up to April 25, 1928. Photograph by Bruce Burns.

GEOLOGY

Exposed along the north bank of Whitebird Creek for several miles occurs the Latah formation which is made up of several hundred feet of fine lacustrine shales and silts interbedded with overlying and underlying Columbia River basalt of Miocene age. At this place the series dips gently to the north and is overlaid by basalt. On the high hill north of the area (see Figs. 2, 3, and 4) the thickness of basalt is more than 1,000 feet. In the valley-like depression where the faults are located, the basalt has been eroded to a thinner capping of 300 feet or less. The basalt also dips gently northward at angles near 15° (see Fig. 4).

Field relations make it seem obvious that displacement has occurred in the solid rock as well as in thick bodies of waste and débris which in spots mantle the area.

EXTENT OF THE FAULTS

Two larger displacements and several smaller ones represent the active faults in the area (see Fig. 1).

Number 1 fault or "crack" extends for 8,200 feet without a break, and No. 2, a parallel fault ranging between 500 and 800 feet farther west, is about 6,200 feet long.

Number 1 fault has two short splits, each less than 100 feet long, and No. 2 has a branch fault which is 1,800 feet in length.

At a point 715 feet north of the north end of No. 1, another fault, 500 feet long, appears which is assumed to be a continuation of No. 1. At a point 410 feet farther a small fissure 125 feet long appears; this is followed by another gap of 195 feet, and then a fissure 1,780 feet in length extends to the base of the steep basalt cliff which flanks the main valley. The total length inferred for this fault is 13,600 feet.

FIG. 3.—Looking north, showing rift and fissure along No. 1 fault on April 25, 1928. Note gentle topography in fault area, and high escarpment at north end of fault. Photograph by Bruce Burns.

Four faults, not longer than 500 feet each, lie north of No. 2 in a curved line, separated by equally large breaks and appear to be potential extensions of No. 2. Future investigations may show these breaks gradually extending to join No. 2.

Five smaller faults approximately parallel to the two major displacements lie in the block between Nos. 1 and 2. The longest of these extends for 600 feet.

Five other faults, approximately at right angles to the major faults, also lie in this block. The longest of these extends about 350 feet. At no place does a cross-fault join the two major displacements.

A similar short displacement occurs on Whitebird Creek about 2,000 feet south of the end of No. 2 fault, and may or may not have some relation to it. It has broken the Latah formation open sufficiently to show a thin vein of lignitic material. This, or another similar lignitic vein, crops out at several places on the high hill of the lake-bed formation which lies north of the highway.

METHODS OF MEASUREMENT

A series of stakes were placed, usually in groups of three, with two on one side of a fault and one on the opposite side. It was neces-

FIG. 4.—Looking northeast from lower slope of high hill at north end of No. 1 fault, whose trace is indicated by black line. Note its independence of topography. Note dipping basalt layers.

sary to drive these stakes entirely into the ground in order that curious tourists might not discover and extract them, and in order to prevent wandering live stock from accidentally disturbing them. This precaution necessitated placing them fairly close to the fault to facilitate relocation for subsequent measurements.

In most cases the stakes were imbedded in the ground at a distance of about 3 feet from the fault fissure. It is obvious that stakes set farther away from the fault would have been more desirable for several reasons, but these reasons were offset by the necessity of relocating the stakes in the short time available at each examination.

A type sample of one of these groups of stakes and the movements represented by different measurements is given in Figures 6

and 7. This set of stakes is located about 50 feet south of the road at its southernmost crossing of the eastern fault. Measurements in Figure 6 assume point *C* to be fixed, which is unlikely, while measurements in Figure 7 indicate a shifting point at *C*. The latter case seems most probable as the distance *B*–*C* varies from 9.6 feet to 10.05 feet and then back again to 9.65 feet, showing that the compressing force on the left side of the fissure may actually have stretched the area between *B* and *C* for an interval, and moved *B* forward. Finally, *C* sprang forward, and *B*–*C* contracted to almost the original distance. The amount of movement varies with the two cases from 2.95 to 2.55 feet between March 25 and November 13, 1928.

FIG. 5.—Looking south along fault furrow, toward Whitebird Creek. Note gentle slopes. Photograph by Bruce Burns.

NATURE OF THE MOVEMENT

The block between the two large "cracks" has moved southward toward lower ground, and as this central block moved down hill, movement was such that it, at places, appears to have moved up in relation to the outer blocks on the east and on the west. At other places the opposite is true. When observed on March 24 and 25, more of the central block showed a downthrow relation. On May 25 and 26, and on June 23, most of the central block showed an upthrow relation. On August 30 and November 13, the downthrow relation was again dominant.

In two localities studied the downthrow and upthrow relations alternated from time to time, so that on one examination side *A* was 8 inches higher than side *B*. At a later date side *A* was 6 inches lower than side *B*. At a subsequent examination the positions were again reversed so that side *A* was 30 inches higher than side *B*. Side *A* was in each instance on the inside block.

The greatest vertical displacement noted was 3.5 feet at several points, but the average displacement was less than 2 feet. The horizontal movement on No. 1 up to March 25 was 4.4 feet. By May 26, this had been increased to 5.9 feet, and on June 23 this was 6.65 feet. By November 13, this distance totaled 7.35 feet with the shifting *C* measurement (see Table I and Fig. 7).

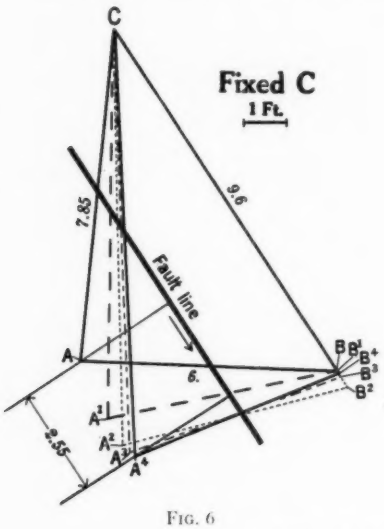

FIG. 6

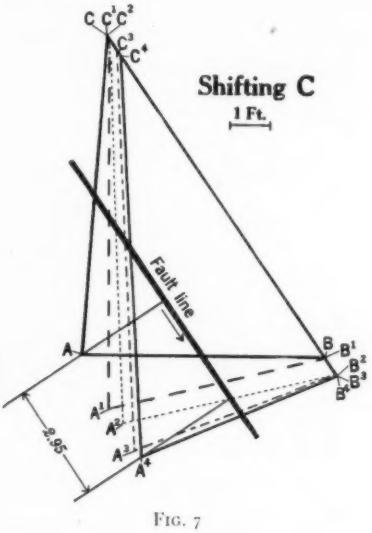

FIG. 7

RATE OF MOVEMENT

Number 1 fault, which has caused an appreciable displacement in the road on several occasions, was first noticed about November 25, 1927, by Mr. Harry Vincent, maintenance engineer, Idaho Bureau of Highways. At this time only a crack appeared, with very little movement. Mr. Vincent stated that he had not observed horizontal displacement until after January 1, 1928.

Mr. Robert Cone, whose farm dwellings are situated on No. 2 fault, also noted No. 1 fault early in 1928. He testifies that horizontal movement along No. 1 fault amounted to approximately 2 feet during March, 1928. Mr. Bruce Burns, of Lewiston, measured a movement of $\frac{3}{4}$ inch in 17 hours on April 25 and 26, 1928 (see Table II).

The writers can testify to much recent movement. At the time of the first visit in March the fresh earth and rock were torn up in deep black furrows along the escarpment of each "crack," and in spite of the travel on the road the marks were fresh where the faults crossed it. The fissures stood slightly open and had a depth of several feet in places.

TABLE I

(See Fig. 7)

	A–B	*A–C*	*B–C*	Movement	Total
March 24	6	7.85	9.6	4.4	4.4
May 25	5.45	9.15	9.6	1.5	5.9
June 23	5.475	9.75	10.05	0.75	6.65
August 30	5.27	9.9	9.75	.5	7.15
November 13	5.19	9.9	9.65	0.2	7.35

Number 2 fault passes under Robert Cone's garage, and parallels the front fence of his yard and garden. He first noticed this fault on November 23, when a horse tied to the fence broke through the

TABLE II

Period	Time in Days	Distance	Rate in Feet per Day
1	125	4.4	0.0352
2	59	1.5	.0254
3	29	0.75	.0258
4	68	.5	.0073
5	43	0.2	0.0046

It is to be understood, of course, that the movement was probably spasmodic, resulting from cumulative stresses.

ground and buried its forelegs where the "crack" had developed. Movement since January, 1928, has caused the garage building, a frame structure, to become so out of plumb and so distorted as to be practically unusable.

CAUSE OF MOVEMENT

Two hypotheses can be advanced for the explanation of these "cracks." One is the creep or landslip hypothesis, and the other is the local gravity-fault hypothesis. In either case the "cracks" represent faults along which movement has occurred and is occurring.

THE LANDSLIP HYPOTHESIS

This hypothesis postulates the area in which the faults occur to be a block, about 16,000 feet wide and at least 25,000 feet long, which has slid off of the escarpment of the high basaltic plateau north of Whitebird Creek. The "cracks," in this case, would represent faults which border landslide material which is creeping down hill. The similarity of dip of beds in the escarpment and in the "slide" could be assigned to coincidence. It is a commonly observed field occurrence that in sliding down hill the beds in the slide material dip backward toward the hill from which they have parted, owing to well-known rotational movement.

Some "trigger" factor must have been present to initiate the movement. This is assigned to unusual water saturation. The block must have been aided in its movement by the presence of a small

TABLE III

Date	Rainfall	Date	Rainfall	Date	Rainfall
Sept., 1926.....	1.8	Oct., 1926.....	2.50	Nov., 1926.....	2.97
Sept., 1927.....	5.84	Oct., 1927.....	2.28	Nov., 1927.....	5.75
Sept., 1928.....	1.75	Oct., 1928.....	2.58	Nov., 1928.....	2.5+

artificial lake or reservoir (see Fig. 1). Its situation at the head of two depressions traversed by faults may have significance. Water from this reservoir and from an unusual amount of rainfall may have initiated slipping of basalt on the underlying shales and clays of the Latah formation.

The movement is believed to have started about November 21, 1927, and the precipitation data shown in Table III are included for evidence. The statistics show that a decidedly unusual amount of rainfall occurred during September, October, and November, 1927. Precipitation data for the year, however, shows less than 27 inches. For the preceding year it was 35 inches. The average yearly precipitation is 29 inches.

In the beginning the writers favored the idea that the phenomena represented some form of landslide, or creep, but a thorough study of the literature during later months has raised some apparently unanswerable objections.

OBJECTIONS

1. The dimensions of the area between the two large faults are unlike those of any slide, creep, or mudflow described in literature. This, of course, may not be significant because this occurrence may be a unique case. Nevertheless, landslide blocks 16,000 feet across are unusual. When movement of material of this dimension occurs it is usually assigned to gravity faulting.

2. The angle of dip in the basalts of the escarpment and in the faulted area is so similar as to suggest a continuous series rather than the exact duplication by coincidence, which is more improbable.

3. The slide, creep, or mudflow would be forced to move on the low gradient of 1 foot in 35. No described creep shows so low a gradient, so far as is known. The Zug[1] mudflow, in Switzerland, has a gradient of 1 foot in 22.

4. If the sector between the two large faults is a slide, creep, or mudflow, there should be a similar amount of horizontal displacement on each side of this block.

5. In a mudflow, slide, or creep, large cracks or fissures should show at the head of the slide. In the Whitebird area there are no fissures cutting across the up-hill end of the moving block.

6. Movement should be more rapid at the head of a slide. This is not true in this block.

7. In a slide the movement should extend to Whitebird Creek. The cracks actually die out at a distance of 2,000 feet away from the creek.

8. The break on one side extends almost twice as far as the break on the other side. In a mudflow these breaks would be expected to bound completely the sides and upper end.

9. The "slide" would have a width of 600 feet and a length in the direction of its movement ranging from 5,500 to 13,600 feet. These dimensions are actually the reverse of typical landcreeps, slides, and mudflows, which usually have their short dimensions in the direction of flow, and a much higher gradient.

10. If this is a slide, it is flowing against the dip of the formations, which is unlikely. If it were made up solely of surficial ma-

[1] Amadeus W. Grabau, *Principles of Stratigraphy* (New York, 1913), p. 659.

terial, such a relationship would be possible, but field relations indicate that the bed rock also is being displaced.

11. The fact that nothing similar to these cracks has occurred in this locality within the memory of man is significant. In a region subject to landslides their phenomena are often repeated in a short period of time and are usually readily recognized by the inhabitants.

THE GRAVITY-FAULT HYPOTHESIS

If the "cracks" are results of local gravity faulting, an earthquake should have occurred at the time of the initial displacement. No resident of this sparsely inhabited country has felt any earthquake. Seismological records[1] show, on the contrary, that an earthquake occurred, which could be located here, at 7:00 A.M., November 21, 1927. Because this was winter time in this region it is unlikely that anyone was awake at that hour in any of the scattered habitations.

Measurements taken from stakes showed the amount of horizontal movement on the fault to be consistent from place to place. This would more likely occur if rock masses were affected rather than unconsolidated surface material. Movement opposite to the dip of the beds indicates faulting rather than sliding. The middle sector between the two large faults appears to have a graben-like relationship to the outside sectors. The dimensions of the block between faults Nos. 1 and 2 suggest faulting rather than landslides, creeps, or mudflows.

The deep-seated nature of the faults is attested by the diversion of underground water flow. Three springs have stopped flowing, and a new one has issued forth. These are all located near the fissures.

Summing up the evidence, the writers are inclined to believe that the "cracks" are active faults in bed rock, but with movements which further investigations may show to be annually influenced by local phenomena.

Further examination and measurements will be continued, to disclose the occurrence and extent of any additional movements in the immediate future.

[1] Communication from James B. Macelwane, S.J., St. Louis, Mo.

ACKNOWLEDGMENTS

The writers are grateful for aid rendered in the field by Messrs. Frank Marsh, Harold MacKinley, and Clarence Myrene, of Moscow; Bruce Burns, of Lewiston; and C. R. Campbell, of Grangeville, Idaho. Thanks are also due to Dr. R. T. Chamberlin and to Dr. J Harlen Bretz, of the University of Chicago, for discussion and criticism rendered during the preparation of the manuscript.

THE ORTHOCLASE-PLAGIOCLASE EQUILIBRIUM DIAGRAM

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ABSTRACT

A new equilibrium diagram for the system Or: Ab: An has been constructed on the basis of the feldspar content of a large number of rocks. It indicates that an increase in the anorthite content of the plagioclase present corresponds to an increase in the possible maximum of orthoclase in the rocks. Thus the eutectic point between orthoclase and albite lies at about 45 Or: 55 Ab, whereas the boundary between the orthoclase and plagioclase fields in the vicinity of andesine is near 70 Or: 30 ($Ab_{70}An_{30}$).

Several equilibrium diagrams have been presented for the system orthoclase: albite: anorthite. J. H. L. Vogt,[1] who has studied the system more thoroughly than any other investigator, has presented the well-known diagram reproduced here as Figure 1*a*. The line *EE'* shows, in the usual manner, the compositions of all liquids which are in equilibrium with both orthoclase and plagioclase crystals, as well as the composition of the liquids from which both orthoclase and plagioclase may crystallize simultaneously. On a three-dimensional composition-temperature model, it is the "trough." Vogt determined the position of the solid portion of the line by a study of the composition of the first feldspar to crystallize in rocks of varying orthoclase-plagioclase content. He found that orthoclase had been the first mineral to crystallize in any rock whose composition is represented by a point lying above the solid line. Plagioclase, on the other hand, developed earlier than orthoclase in the rocks lying below this line. The dotted extension of the line is an extrapolation. If there is no uncertainty as to the sequence of the beginning of crystallization, and if equilibrium conditions were attained during the crystallization of the rocks studied, this line should approximate the boundary between the orthoclase and the plagioclase fields.

[1] J. H. L. Vogt, "Physikalisch-chemische Gesetze der Krystallisationsfolge in Eruptiv-gesteinen," *Min. Petr. Mitt.*, Bd. XXIV (1905), pp. 437–543; "The Physical Chemistry of the Magmatic Differentiation of Igneous Rocks," *Norske Videnskaps Akademi* (Oslo, 1926), Pt. II, p. 58.

N. L. Bowen[1] has recently pointed out that "it is unlikely that the eutectic between orthoclase and anorthite, if there were one, would lie very far from orthoclase with its melting-point (incongruent) at 1170° and that of anorthite at 1550°." He has presented an alternative diagram, which has been reproduced here as Figure 1*b*. Resting principally on his conviction that there is no eutectic between orthoclase and anorthite, but a reaction point close to orthoclase, this diagram is intended to indicate in a general way the position of the field boundary. While this diagram is of the same type as that presented by Vogt, the two boundaries have only one point in common: the eutectic between orthoclase and albite.

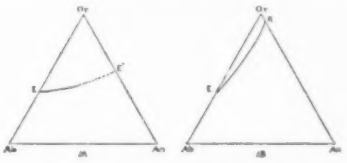

FIG. 1*a*.—The orthoclase-plagioclase equilibrium diagram after Vogt (1926).

FIG. 1*b*.—The orthoclase-plagioclase equilibrium diagram after Bowen.

I have attacked the problem by a method which depends, like that of Vogt, upon the characters of the rocks themselves. It has, however, resulted in a diagram (Fig. 3) very different from the one derived by him, although it is strikingly like that which Bowen has inferred from theoretical considerations.

The theory on which the method is based is as follows: If there is an effective boundary between the fields of orthoclase and of plagioclase, and if rocks are derived chiefly by fractional crystallization from original magmas poor in potash, the composition of any magma should tend to approach the boundary. In other words, there should be a great many rocks on the plagioclase side of the boundary, and more of these should lie in the vicinity of the boundary than in any other equivalent area of the diagram. (Moreover, any rock whose composition lies in the orthoclase field requires some special explanation, since a solution cannot, under equilibrium conditions, cross the field boundary.) Conversely, if a line can be found along which there are many points representing rock compositions, it is reasonable to suppose that this is the boundary line. Line *EE'* of Figures 2 and 3 is such a line.

[1] N. L. Bowen, *The Evolution of the Igneous Rocks* (Princeton University Press, 1928), p. 229.

The data upon which the new equilibrium diagram is based are shown in Figure 2, which gives the normative feldspar content of certain rocks whose analyses have been published by H. S. Washington.[1] In constructing the diagram, it was necessary to exercise a certain discrimination. The figure shows the composition of practically all available rocks containing more than 40 per cent orthoclase in the total feldspar content and more than 20 per cent anorthite in the plagioclase. The orthoclase-rich rocks containing a more sodic plagioclase were all taken from the groups whose members contain less than 37 per cent quartz (orders Quarfelic and Dofelic), since a vast majority of those containing the more calcic feldspars also fell in these orders. Thus the rocks have a certain degree of uniformity with respect to their non-feldspathic constituents. In the case of these more sodic rocks, a further selection was made, in that only the fine-grained rocks and glasses were plotted. As N. L. Bowen[2] has pointed out, such rocks are more likely to approach possible liquids than are the coarse-grained types, which, in this case, showed a wider range of variation than did the fine-grained and glassy rocks. Thus the rocks omitted from the diagram are those containing (1) more than 37 per cent quartz and (2) the coarse-grained representatives of the highly sodic group. Some members of these omitted groups, as well as some of the anorthite-free rocks which were plotted in Figure 2, lie in the orthoclase field; that is, they appear to have crossed the field boundary. Had the rocks of these omitted groups been plotted, their presence would have obscured the field boundary near the orthoclase-albite side of the triangle, but they certainly

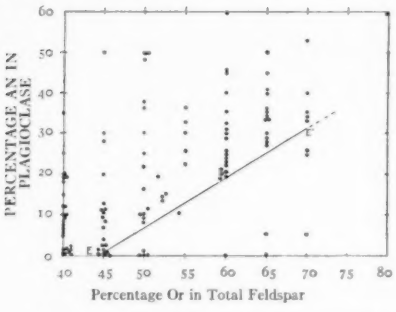

FIG. 2.—Feldspar content of 121 rocks whose orthoclase : total-feldspar ratio exceeds 0.40.

[1] H. S. Washington, "Quantitative Classification of the Igneous Rocks," *U. S. Geol. Surv. Prof. Paper No. 99* (Washington, 1917).

[2] *Op. cit.*, p. 94.

would not have obliterated it. The formation of these potash-rich rocks will be dealt with in a later paper.

In recalculating the normative feldspar content of the rocks to 100 per cent, the orthoclase content was obtained to the nearest 5 per cent and that of the anorthite within an error of about 2 per cent. These approximations are easily within the limits of error inherent in the method itself. When most of the rocks had been plotted, it became apparent that there were very few rocks lying near the boundary where it crosses the line representing 55 per cent orthoclase. Accordingly, the rocks which lie on either side of the gap were calculated more carefully to see whether the gap might have been dependent upon the approximations made. This process rendered the gap slightly less conspicuous but still quite obvious.

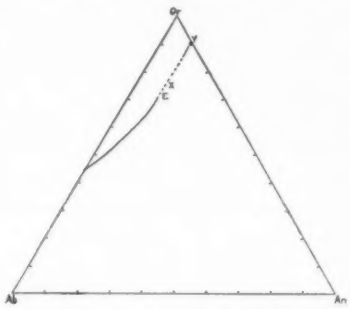

FIG. 3.—The orthoclase-plagioclase equilibrium diagram derived from the data of Figure 2.

When the initial trial curve of Figure 2 was drawn, it was found that from the albite-orthoclase side of the diagram to a point where the plagioclase is an andesine, the slope of the curve was everywhere very nearly such that an increase of 6 per cent of anorthite in the plagioclase corresponded to an increase of 5 per cent of orthoclase in the rocks located near the boundary. Accordingly, the curve was smoothed to this slope and extrapolated with the same slope to a point (X) corresponding to 80 per cent of orthoclase and 20 per cent of $Ab_{57}An_{43}$. Obviously, if the curve continued with this same slope, the point representing 100 per cent orthoclase would be reached when there was still a considerable amount of albite in the plagioclase.[1] On the other hand, one might suppose that the boundary curve of Figure 3 approaches asymptotically the line corresponding

[1] Regarding this possibility, N. L. Bowen wrote, in a letter of March 19, 1929, "Perhaps your finding . . . . is no accident, but actually the condition obtaining in rocks, on account of the near coincidence of these points with Or."

to, say, 92 per cent orthoclase. The lines *XY* of Figures 2 and 3 (they are, of course, the same line, on different co-ordinates) are drawn on this assumption. However, the question of the curve between X and the orthoclase-anorthite side of the triangle is largely academic, for rocks whose compositions lie in that area are exceedingly rare, if not quite unknown.

A relatively minor point of interest which Figure 2 brings out is the fact that there is as much foundation in this study for supposing that the eutectic point between albite and orthoclase lies at 45 Or: 55 Ab as there is for accepting the more commonly stated ratio 40:60. In drawing the boundary *EE'* of Figures 2 and 3, I have chosen the former ratio, chiefly because it produces a smoother curve.

An unsuccessful effort was made to apply Vogt's method involving a study of the sequence of the beginning of crystallization. When a number of andesine-orthoclase and labradorite-orthoclase extrusive rocks had been plotted, and the composition of the first mineral or minerals to crystallize from each was indicated, it appeared that the order of crystallization was inconsistent.

Although Vogt has obtained consistent results for the boundary between the sodic plagioclase and orthoclase, these results are in the main at variance with those which I have obtained. While I have no explanation to offer for this difference, it should be pointed out that the case has a close analogy in the system diopside-plagioclase. The equilibrium diagram[1] for that system has been thoroughly worked out in the Geophysical Laboratory. Moreover, the composition of studied suites of rocks, and the composition of the basic rocks in general confirm the implications of the diagram. But imagine the diagram which might be derived from a consideration of the diabase texture of the plateau basalts in which diopside has every appearance of having been the last mineral to crystallize!

In conclusion, I wish to thank Dr. N. L. Bowen, of the Geophysical Laboratory, who has read this paper in manuscript and has offered some valuable criticisms.

[1] N. L. Bowen, *op. cit.*, pp. 46–47.

REVIEWS

Geologic Story of the Genesee Valley and Western New York. By H. L. FAIRCHILD. Rochester, N.Y.: Scrantom's, Inc., 1928. Pp. 215; figs. 187.

The span of life is brief. Few may stand on the pinnacle of nearly fifty years of substantial achievement and contemplate the uncertain, often devious, pathway that has led to the pinnacle. Still fewer can picture in lucid and fascinating description the course of the pathway and the results of the upward climb. Professor Fairchild, in his *Geologic Story of the Genesee Valley and Western New York*, not only places before the lay reader in facile, readable English the results of his nearly half-century of intensive study of the geology of a region renowned for its natural beauty, but also takes him back through geologic time and unfolds in word and picture the history of a region classic in geology.

The first four chapters are introductory and acquaint the reader with the fundamental principles and facts essential to the understanding and appreciation of simple geological description. Chapter i is an outline of the geologic history of western New York in which the sequence of larger events is epitomized. In chapter ii the formation of rock strata is simply described, and in chapter iii there follows a description of the geologic time table and the position the rock strata of western New York occupy in the table. Chapter iv is a brief discussion of the important groups of animals and plants with especial reference to life of the early Paleozoic seas that invaded the New York region.

The stratigraphy of western New York is described in seven chapters. In the first of these chapters the salient features of the stratigraphy are outlined and illustrated with a geologic map of western New York and with a columnar section. Three chapters are devoted to the description of the early and middle Silurian strata, the classic section exposed in the Rochester Canyon being used both as a guide and for illustrative purposes. Comparison of this section is made in considerable detail with the magnificent Niagara section. The numerous photographs that illustrate the description are remarkable, both for their excellence and for their pertinence to the subjects interestingly discussed. The Salina formation and the origin and physical features of its widely known salt deposits are

next described. Two beautifully illustrated chapters are devoted to the description of the Devonian formations, the majestic Portage Canyon of the Genesee, reproduced in several photographs, serving as the guide for the description of the Upper Devonian formations and particularly the Portage shales. Tables showing the latest refinements in the stratigraphic subdivisions of western New York are introduced in the chapters as an aid to the reader in following the discussion of the stratigraphic sequence. Each chapter contains a description with illustrations of the chief animal types that swarmed the seas of the time.

In the chapter on the physical events since the close of the Devonian, the erosional history of western New York is traced and the successive erosion cycles with the development of the peneplains are described. The chapter is closed with a summary of the major diastrophic events between the Devonian and the present.

The ancient life of the Genesee country is described in word and picture in chapter xiii, particular attention being given to the forests of the late Paleozoic era and the hordes of reptiles that must have inhabited the region during the Mesozoic era. The chapter closes with an interesting account of the development of mammalian life during the Tertiary.

In the description of the evolution of the Genesee River the author again presents in popular language his views of the development of drainage in central and western New York. From the original, consequent, southward drainage the author traces the history through the development on weak belts of rock of the major subsequents, Ontarian and Erian rivers, which flowed westward and the extension of their tributaries southward into Pennsylvania, converting by stream capture the western New York drainage from the original consequent to the Tertiary obsequent development. The carving of the Genesee and the other remarkable Finger Lake valleys is described and their relation to the general drainage plan depicted. The chapter closes with a description of the effect of the Quebec glacier in its advance and in its retreat on the drainage, and the general influence of glaciation in producing the present "discordant and unreconciled" stream flow.

The description of the work of the Quebec ice-sheet occupies two beautifully illustrated chapters. In the first chapter the causes leading to the initiation of the ice-sheet are briefly sketched; its advance over the region with moderate erosion, the transportation and deposition of débris, and the final retreat of the glacier are successively described. The lack of evidence of multiple glaciation is brought out with the suggestion that the Quebec ice-sheet may have "existed through all the length of the

Glacial Period, with only moderate changes in its extent." The glacial features, till, drumlins, kames, eskers, moraines, etc., are briefly but clearly discussed and illustrated in topographic maps and in photographs.

Two chapters are devoted to glacial lakes, in the study of which Professor Fairchild has spent many years. The history of the remarkable succession of lakes impounded in the Genesee Valley by the receding ice-sheet is outlined, together with the relation of these local waters to the glacial great lakes which invaded New York during the final stages in the retreat of the ice from the state. A chapter is devoted to the history of Lake Dawson and Lake Iroquois. The phenomena associated with the life of these lakes, particularly Iroquois, are remarkably preserved and easily accessible to residents of Rochester. The history is depicted also in a series of maps, one of the most interesting of which is the reproduction of the Rochester quadrangle showing the location of the glacial features.

In chapter xix, following the chapters on the glacial lakes, the origin and history of Gilbert Gulf are described and the causes that transformed this great inland sea into the fresh-water sea, Lake Ontario, are discussed. In this chapter the author takes up at some length the postglacial tilting of the New York region. The making of the Rochester, Portage, and Mount Morris canyons in the brief post-glacial interval are discussed in two chapters with appropriate illustrations.

In the chapter on "Existing Lakes" the writer discusses the general distribution and life-history of lakes, the origin of salt lakes and lake basins, the geologic work and climatic influence of lakes, and causes of changes in lake levels. Lakes due to glaciation are classified as (1) morainal or drift barrier, (2) kettle basins, (3) cataract or plunge basin, and (4) ice erosion. No examples of the last class are cited. The Finger lakes "are due to drift fillings in the ancient north-sloping valleys," and "Lake Ontario must have similar origin." The remarkable and unusual cataract lakes southeast of Syracuse are illustrated and described.

In the final chapter the recently extinct life of western New York is briefly surveyed with a short account of the numerous finds of mastodon and mammoth in the state. The chapter closes with a glance at geologic processes now in operation in western New York and a forecast of future events.

The introduction and subscript of the book are embellished with two poems by the late T. T. Swinburne, the distinguished poet-laureate of the Geresee.

Few books have appeared in popular geology as clearly and enter-

tainingly written and as beautifully illustrated as is the *Geologic Story of the Genesee Valley and Western New York*. The perusal of its pages will prove both pleasurable and profitable to the scientist and layman.

ALBERT W. GILES

The Pennsylvanian System in the Ardmore Basin. By C. W. TOMLINSON. *Oklahoma Geological Survey Bull. 46*. Norman, Oklahoma, March, 1929. Pp. 79; pls. 16; maps 4; figs. 3.

The Ardmore Basin is in southern Oklahoma, southwest of the Arbuckle Mountains. This report discusses many interesting features, such as the great thickness of sediments, the records of two episodes of Pennsylvanian orogeny, and the variable paleogeography of that period. The formations in the general region, ranging from Cambrian to Permian, with overlaps of Cretaceous (Trinity) beds, are shown on a geologic map (Plate XVII). The Pennsylvanian is divisible into at least sixty-three lithologic units, which are grouped as follows:

Hart limestone: 0–200 feet, reworked Ordovician limestones

Vanoss formation (lower Pontotoc series):

North of Arbuckle Mountains it consists of several hundred feet of coarse arkosic limestone conglomerate.

South of Arbuckle Mountains it consists of 50–200 feet of red shale and coarse arkose.

Unconformity.

Hoxbar formation: 4,000± feet, shales with limestones and sandstones. Unconformity.

Deese formation: 7,000± feet, sandstones, chert conglomerates, and shales, with few limestone beds.

Dornick Hills formation: 1,500 feet (at north) to 4,000 feet (at south), shales, limestones, limestone conglomerates, and sandstones.

Unconformity.

Springer formation: 3,000–3,500 feet, black bituminous shale with four sandstone members.

(Mississippian—Caney shale)

Sedimentation features of especial interest are: Caney shale boulders (pp. 25–27); limestone conglomerates (pp. 30, 43); crossbedded limestone (pp. 33, 45); shells filled with chert (pp. 33, 38); chert conglomerates (p. 35); conglomeratic limestone (p. 45); algal(?) limestone nodules with nuclei of limestone, chert, etc. (p. 52); and Red beds (pp. 61–66).

Tomlinson agrees with Ulrich and Miser that the boulders in the lower Caney shale (Mississippian) are ice-borne. He determines the source to

be to the southeast, instead of in the Arbuckle Mountains, because these mountains were not uplifted before the early Pennsylvanian and the boulders disappear toward the mountains. A similar source and origin is ascribed to boulders in the upper part of the Caney shale.

The Red beds are interpreted as the piedmont alluvial-plain facies, on both flanks of the Arbuckle-Wichita uplift, of marine beds to the north and south into which they grade.

The first orogeny occurred in early Pennsylvanian time, after the Springer epoch. As a result, shales more than a mile thick were eroded from the Criner Hills area, with exposure of the Viola (Ordovician) limestone; and an island or submerged range existed here to Deese time. Granite peaks were produced in the Wichita Mountain area and in the Nocoma district to the south, and the northern Arbuckle Mountains were probably uplifted.

Severe orogeny occurred in late Pennsylvanian (post-Hoxbar) time, during which the Wichita Mountain area was refolded and faulted; and the Arbuckle Mountains were intensely deformed and deeply eroded. The crustal shortening was about 40 per cent, or more than 16 miles. Erosion beveled 25,000 feet of strata, into the Reagan sandstone (Cambrian), before deposition of the Pontotoc series was begun in latest Pennsylvanian time.

Structural axes of the two epochs of deformation are shown on a map (Fig. 2). They have subparallel northwest trends. A discussion is given of the reliability of lithologic methods of correlation in this area (pp. 66–69), and the application of these methods in the field are shown on three maps (Plates XVIII–XX).

The report contains an Appendix of lists of fossils obtained up to 1928 from the different Pennsylvanian members, with bibliographic references. A person not familiar with the stratigraphy of the region has some difficulty in following some of the discussion. The lack of an Index to the bulletin is regrettable.

ARTHUR BEVAN

Agricultural Geology. By FREDERICK V. EMERSON; revised by JOHN E. SMITH. New York: John Wiley & Sons, 1928. Pp. 377 and Appendix; figs. 271. $3.25.

This is a book clearly designed for teaching, not as a reference. The outstanding faults in an otherwise very useful text are poor editing and a frequently illogical arrangement. Careless wording is unfortunately

common. Thus, on page 17, there is a gap in presentation in the sequence: "Rocks may be divided into two class. *Igneous* rocks with a high percentage of silica are termed acidic; those with high percentages of iron, calcium, magnesium or sodium are termed basic"; but what if the rocks are not igneous? Again, in discussing "clastic" rocks, under the heading "The Agents," appear the following subheads: "Sandstones," "Chemical Composition," "Conglomerate," "Limestone," "Varieties," etc.; the critical reader finds it difficult to see in what sense these terms are coequal.

In an agricultural geology, it is surprising to search vainly for definitions of "silt" and "loam"; to see natural nitrates as fertilizers treated in nine lines (with no mention of artificial sources), whereas phosphates receive almost that number of pages; and to read a discussion of apatite among the minerals of the mantle rock whereas the kaolin-like minerals are not even mentioned. These patent shortcomings suggest undue haste in the writing; a little contemplation should have made them apparent.

Most of these mistakes have been carried over from the first edition. The second edition failed to eliminate them, yet it represents a great improvement. The addition of brief sections on magmatic segregation, pegmatites, and related subjects; the introduction of the section on the uses of rocks; and the addition of a soil-map list as Appendix—these are all welcome innovations. The further expansion of the discussion of soil minerals (pp. 97 ff.), some consideration of the atmosphere (composition, moisture content, and perhaps even its movements), and a treatment of springs more extensive than the short paragraph on page 155 would seem appropriate in a text for agricultural students.

When all this is said the book remains unusual in its emphasis on the relation of geology to soils. Especially commendable are the numerous block diagrams and the constant reference to concrete examples, unique in that they are selected from the domain of soil geology; these must leave the student with actual images, instead of abstract concepts, and convey confidence in the reality of the science.

CHAS. H. BEHRE, JR.

Fifty Years' Progress in Geology—1876–1926. By E. B. MATHEWS, ed. "The Johns Hopkins University Studies in Geology," No. 8. Baltimore: Johns Hopkins Press, 1927. Pp. 161.

The contents of the volume consist of a series of papers presented in the Geological Conference during the celebration of the fiftieth anniversary of Johns Hopkins University.

W. S. Bayley writes on "Contributions of Hopkins to Geology," in which he stresses the part played by Hopkins in the introduction of the microscope into American geology. George Otis Smith in a short paper entitled "Geology at Work" discusses the increase in the number of workers who make geology their field, and the present realization of the practical importance of the science. He deplores the fact that the general public has no conception of the scope of geology.

"Fifty Years Progress in Petrography and Petrology" is the title of a paper by F. Bascom. This constitutes a valuable history of the development of these studies. The contributors to progress of petrography and petrology are discussed, and their contributions enumerated. Numerous foreign, as well as American, writers are included.

D. W. Ohern's paper on "Fifty Years of Petroleum Geology" is a historical treatment of that field. Much material of interest is presented here in very readable fashion.

"Progress of Ore Genesis Studies" is discussed by B. L. Miller. He tells of the past and present views on ore classification, secondary enrichment, metasomatism, magmatic processes, zonal arrangement of ore minerals, metallogenetic provinces and epochs, and chemical and biological contributions to ore genesis.

E. B. Mathews, under the title "Progress in Structural Geology" writes of the history of this branch and the recent use of experimental work in its study. A paper by M. I. Goldman on "Progress in Sedimentation Studies" and one by W. P. Woodring on "Progress in Paleontology" were not available at the time of printing.

C. C. B.

Geology and Mineral Resources of the Dixon Quadrangle. By R. S. KNAPPEN. *Ill. State Geol. Survey, Bull. No. 49.* Urbana, 1926. Pp. 141; maps 2.

The Dixon Quadrangle includes part of Ogle and Lee counties in the northern part of Illinois. The oldest rocks exposed are Lower Ordovician in age, but the Cambrian has been penetrated by drilling. The youngest marine formation is the Ordovician Galena dolomite. The Maquoketa shales presumably once lay over the Galena dolomite, but they have been completely removed from the Dixon Quadrangle by erosion. The region was covered by Pleistocene glaciers, tills of the Illinoian and Iowan stages being found. The glaciation radically modified the drainage, and a map showing the differences between pre-Pleistocene drainage

and present drainage is given opposite page 98. The major structural feature of the quadrangle is the La Salle anticline, which began to form in St. Peter time. The physiography and economic geology are discussed in separate chapters.

C. C. B.

Southern California Geology and Los Angeles Earthquakes. By R. T. HILL. Southern California Academy of Sciences, 1928. Pp. 232; maps 4. $5.00.

This book is a reply on the behalf of Los Angeles to Bailey Willis' prediction of an earthquake in southern California within a short time. Unfortunately, it is of a strongly partisan character. It is unscientific in that it starts with the avowed purpose of proving that there will be no such earthquake, and only evidence in that direction is considered. That the book was rushed to press is shown by the careless proofreading and by the poor plates. It is surprising and to be regretted that the Southern California Academy of Sciences should be a prime mover in a partisan effort of this sort.

C. C. B.

Stratigraphy of China. Part II: *Mesozoic.* By A. W. GRABAU. Peking: Geological Survey of China, 1928. Pp. 774; text figs. 755; pls. 9.

As in the earlier volume on the Paleozoic, the Eurasian continent has been treated as a unit. The Mesozoic marine faunas of Europe, according to Grabau, originated in the Indian and Pacific oceans and migrated through the geosynclines of Asia. Each period of the Mesozoic is treated as a unit and described completely. A discussion of the tectonics and geosynclines of the period opens each chapter. This is followed by a summary of the stratigraphy of the system in parts of Eurasia other than China. The main bulk of each chapter consists of descriptions of the stratigraphy, paleontology, and correlations of the Mesozoic deposits in individual regions of China. The discussion of the Cretaceous is divided into four chapters: one each for the Lower Cretaceous, the Middle Cretaceous, the Upper Cretaceous, and the continental deposits of the Cretaceous.

One is impressed by the great volume of material presented and by the tremendous scope of Grabau's bulletin. *Stratigraphy of China* is a valuable reference book for every geologist.

C. C. B.

Geology, Oil and Coal Resources of the Oregon Basin, Meeteetse, and Grass Creek Basin Quadrangles, Wyoming. By D. F. HEWETT. *U.S. Geol. Survey, Prof. Paper 145.* Washington, 1926. Pp. 111; pls. 32.

The area discussed in this report lies in the western part of the Big Horn Basin. Several producing oil fields are located within the boundaries of the quadrangles. Only Cretaceous and Eocene rocks are exposed, but drilling has proved the presence of thick Paleozoic and Lower Mesozoic sediments. The lithology of each of the exposed formations is described, and lists of the fossils collected from them are given.

Hewett observed that the pebbles of the Fort Union bear numerous percussion marks. He draws the basal line of the overlying Wasatch formation below the bottom of the lowest conglomerate which bears pebbles on which the percussion marks have been obliterated by reworking. Lithologic studies of the Fort Union and Wasatch formations show that they derived their sediments from areas of granitic and cherty rocks. The proportion of granitic material was appreciably higher in Upper Fort Union time.

Hewett argues against the hydraulic theory of migration and accumulation of oil, chiefly on account of the lenticularity of the sands of the Frontier sandstones, which are the main reservoir rocks of the area. The stratigraphic position and distribution of coal beds is discussed in some detail. Areal geologic maps are found in the pocket on the back cover.

C. C. B.

Report on the Geology of the Zanzibar Protectorate. By G. M. STOCKLEY. Government of Zanzibar, 1928. Pp. 126, maps 12. 12*s.* 6*d.* net.

The Zanzibar Protectorate lies near the east coast of Africa just south of the Equator, and consists of two islands, Zanzibar and Pemba. The exposed rocks of Zanzibar consist of 480 feet of Pliocene clays and limestones, and 105 feet of Pleistocene limestone. Raised beaches occur locally. The lowest rocks in Pemba are of Lower Miocene age, with a maximum thickness of 350 feet. As in Zanzibar, there are Pleistocene limestones. This *Report* shows that there is no crystalline core in either of the islands such as was formerly supposed.

Pemba is supposed to have been separated from the mainland during the rift faulting at the close of the Miocene. Zanzibar maintained a connection with the mainland until the Pleistocene. These conclusions are

based upon zoölogical evidence. The absence of raised beaches and the occurrence of drowned valleys upon the island of Pemba show that it has been sinking for some time.

The publication may be obtained from the Crown Agents for the Colonies, 4 Millbank, Westminster, London, S.W. 1.

C. C. B.

Paleontological Contributions to the Geology of Western Australia. By R. W. BRETNALL, F. CHAPMAN, and L. GLAUERT. *Western Australia Geological Survey, Bull. 88.* Perth, 1926. Pp. 72, pls. 4.

Bretnall describes one new genus and seven new species of Bryozoa from the Carboniferous. Chapman lists the fossils found in the Negri series of the Kimberley area and concludes that they are Middle or Upper Cambrian in age. Glauert lists all the known fossil forms of Western Australia by period and by family.

C. C. B.

Contributions to the Paleontology of the New Zealand Trias. By OTTO WILCKENS. New Zealand Department of Scientific and Industrial Research, Geological Survey Branch, *Paleontological Bull. 12.* Wellington, 1927. Pp. 65, pls. 10.

Only the upper part of the Triassic is represented in New Zealand. The fauna is mainly brachiopods and pelecypods, cephalopods being rare. Twenty-two new species are described here, and most of the known forms are figured.

C. C. B.

Paysages et Problèmes géographiques de la Terre américaine. By DOUGLAS W. JOHNSON. Paris: Payot, 1927. Pp. 248; text illus. 79; figs. 52. Fr. 40.

This publication is based upon the lectures given as exchange professor at certain French universities. Certain striking features have been selected for discussion. The topics of the various chapters are: "Landscapes of American Valleys," "The Region of the Grand Canyon of the Colorado," "Glacial Landscapes of the Mountains of the West," "Landscapes of the Atlantic Coast," "Application of the Principles of Physical

Geography to Some Juridical Problems in America," "Rectilinear Shore-Lines of Acadia and of New England," "Stream Piracy in the Region of Tallulah," "The Form of Nantasket Beach."

The presentation is effective, and the plates and figures are excellent.

C. C. B.

On Some Rock-forming Algae from the Younger Mesozoic of Japan. By HISAKATSU YABE and SHIRÔ TOYAMA. "The Science Reports of the Tôhoku Imperial University," 2d Ser. (Geology), Vol. XII, No. 1. Sendai, Japan, 1928. Pp. 12; pls. 6.

Some interesting rock-forming Algae of the Jurassic and Cretaceous are here described. All of the species and four of the genera are new.

C. C. B.

The British Carboniferous Producti. II. *Productus (sensu stricto); Semireticulatus and Longispinus Groups.* By H. M. MUIR-WOOD. "Memoirs of the Geological Survey of Great Britain" (Paleontology), Vol. III, Part 1. 1928. Pp. 217; pls. 12; text figs. 35.

The work here given is a continuation of the researches of Ivor Thomas on the British Carboniferous *Producti*. Miss Muir-Wood discusses the morphology of the genus at length and gives much valuable historical material of the subgenera. She redefines the genera *Productus*, *Avonia*, *Buxtonia*, *Proboscidella*, and *Etheridgina*, and establishes a new genus, *Sinuatella*. The larger part of the volume consists of descriptions and redescriptions of species, nineteen of them new to science.

C. C. B.

Palaeogene Fossils of the Island of Kyûshû, Japan. By T. NAGAO. "The Science Reports of the Tôhoku Imperial University," 2d Ser. (Geology), Vol. XII, No. 1. Sendai, Japan, 1928. Pp. 140; pls. 17.

The fossils here described are from beds, several thousand feet thick, of Eocene and Oligocene age. The forms are all marine and represent 201 species, most of them new. They are well figured and described.

C. C. B.

Geologic Map of the State of New Mexico. By N. H. DARTON. Geologic Atlas of the United States, U.S. Geol. Survey, 1928.

This is an excellent and very welcome map of a little-known state. The geology is mapped by formations, given in colors of unusually good contrast. The map shows streams and culture and is contoured at 100 meters. All features are clearly shown, and the printing is perfect.

C. C. B.

Plants as Indicators of Ground Water. By O. E. MEINZER. *U.S. Geological Survey Water Supply Paper 577.* Washington, 1927. Pp. 91, figs. 15, pls. 12.

The importance of finding ground water in arid regions is recognized, and plants of certain species are excellent indicators of its presence. Those species of plants which live only where there is ground water at shallow depths are singled out and described. The probable depth of the ground water can be guessed at by the presence or absence of certain types. The usual maximum depth from which plants can raise water is fifty feet. There is also a relationship between the kind of plants that grow in an area and the quality of the underlying water, but the criteria are not definite. The quantity of ground water present can be determined approximately by calculating the number of plants and the rate of transpiration of the species. Meinzer's work is of great economic value, and his results are important and well organized.

C. C. B.

Petroleum and Coal. By W. T. THOM, JR., Princeton University Press, 1929. Pp. 223; figs. 40.

Dr. Thom, associate professor of geology at Princeton University and formerly geologist in charge of coal and oil investigations for the United States Geological Survey, is especially well qualified to write with authority upon the rôle played by coal and oil in modern civilization. In this short book the story of the origins of these fuels, their distribution, and their probable future importance is interestingly told, and the narrative is not written from the national but rather from the world point of view. The book should furnish available supplementary reading for courses in economic geology, and will prove of interest not alone to the geologist, but to the economist and the student of international affairs as well.

E. S. B.